■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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OF INTEREST TO MANAGERS

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This issue contains the annual Status and Trends articles plus some encouraging highlights from Delta Water Project Operations for the first quarter of the year outflows. Due to furloughs and staff vacancies , several articles normally part of this issue will be published in the Summer or Fall Issues, including the San Francisco Bay Study contributions on estuarine and marine shrimps, crabs and fishes.

In the “Highlights” section, **Bob Fujimura** describes how to access, via the web, up-to-date salvage data and summary graphics. The web links provided will allow managers and researchers to rapidly examine graphically both current and historical patterns of salvage, and facilitate water management decisions. These links also allow all or portions of the 1993 to present salvage database to be downloaded.

In the second Highlights article **Reza Shahcheraghi** and **Andy Chu** summarize Delta outflows and water project operations for the first quarter of 2011. One aspect not emphasized is the substantial contribution of San Joaquin River (SJR) flows to total outflow. In 2011, SJR flows comprised about 20-30 percent of Delta outflows as compared with 10 percent in a typical year. These high SJR flows created conditions that reduced smelt salvage. You’ll need to use the links provided by Bob Fujimura or wait until next year’s newsletter for the actual data.

Similar to past years, the Status and Trends section begins with an article on flows and exports for water year 2010 to set the stage, because outflow remains a strong driver of estuarine processes. **Reza Shahcheraghi** and **Andy Chu** begin the section with a retrospective of the outflows and exports for water year 2010. Both outflows and exports increased modestly in 2010 compared to the previous 3 water years. Subsequent articles step through the food web from lower to higher trophic levels describing abundance trends of similar taxa.

Our look at primary producers (phytoplankton) focuses on the low salinity zone of the estuary, a biologically important salinity range for invertebrates and fishes, particularly delta smelt. **Tiffany Brown** investigated chlorophyll concentration and phytoplankton abundance occurring from 2008 through 2010. She found increasing phytoplankton densities across the three years, but only weak spring blooms based on chlorophyll concentrations. Recently initiated (2008) speciation of phytoplankton will provide important information in the future as we learn more about the “quality” of phytoplankton taxa as zooplankton food.

IEP’s Environmental Monitoring Program (EMP) documents changes in the composition, abundance, density, and distribution of the macrobenthic biota within the upper San Francisco Estuary. **Heather Fuller** summarizes 2010 benthic monitoring results, describing monthly changes in dominant phyla (Annelida, Arthropoda and Mollusca) by region and provides identities of dominant taxon/taxa for each phylum. As expected the Asian clams *Corbula amurensis* and *Corbicula fluminea* made the top 10 list, as did several amphipods, a couple of which may be in te top 10 of young striped bass diet items.

Moving higher in the water column and the food web, copepods and mysid shrimp comprise important foods for young fishes, and for delta smelt throughout its life. **April Hennessy** describes somewhat improved responses in copepod and mysid abundance trends in 2010. Abundance decreased for the important spring copepod *Eurytemora*, but increased for another, *Sinocalanus*, though *Sinocalanus* has a reputation for being difficult for young fish to catch. *Pseudodiaptomus*, an important summer/fall fish diet component, was up modestly in both seasons. Mysid shrimp become an important food source for longfin smelt beginning in late spring and for striped bass in summer. The dominant upper estuary mysid shrimp, *Hyperacanthomysis longirostris,* increased modestly in spring and sharply in summer 2010. April’s results suggest a stable or improving feeding environment in spring 2010, and possibly a better situation later in the year for fishes eating *Pseudodiaptomus*, like delta smelt, and those that grow to consume mysids like young striped bass and longfin smelt.

One of the repercussions from the State’s hiring freeze and furlough program has been staffing shortages resulting in data processing and analyses delays for a number of programs. In particular, San Francisco Bay Study fish and invertebrate trend reporting will be delayed until a later newsletter issue. Upper estuary pelagic fishes trends were reported for the Summer Townet, Fall Midwater Trawl (FMWT) and USFWS Beach Seine by **Dave Contreras, Virginia Afentoulis, Kathryn Hieb, Randall Baxter and Steven Slater.** Of significant management concern is the continued very low abundance of the

4 Pelagic Organism Decline fish species: delta smelt, longfin smelt, age-0 striped bass and threadfin shad. Juvenile American shad also remained near record low abundance and splittail abundance for FMWT was zero; however, a strong splittail year-class was evident in the US Fish and Wildlife Service beach seine survey. The high splittail spring abundance in the beach seine and low abundance in predominantly pelagic trawling during fall suggestion that splittail are using pelagic habitat less or differently in recent years. Along a similar vein, longfin smelt distribution continues to show the post-clam shift to higher rearing salinities in fall.

The next two articles focus on juvenile and adult Chinook salmon and represent expanding coverage upstream of the estuary for the newsletter. First, **Robert Vincik** describes juvenile Chinook salmon migration timing race by race for most of the migratory period during the current water year, 2011. These Knights Landing catch data are typically reported week by week to the Data Assessment Team and provide an early warning when traps detect pulses of protected races migrating toward the Delta. As you can see, based on catch, juvenile winter-run and spring-run Chinook salmon migration timing was highly variable. Second, **Jason Azat** updates adult Chinook salmon ocean harvest and "escapement" trends through 2010. Predicted increasing returns, which allowed for limited commercial and recreational seasons, materialized in most cases, though winter-run and spring-run returns remained low.

As river flows increased in 2010, so did exports and the potential for fish entrainment. During the water export process, some fishes moving with the water flowing toward the pumps (i.e, entrained) are mechanically diverted from the export flow and "salvaged", to be returned to the western Delta. Trends in salvaged fishes provide additional insight into Delta fish abundance, particularly for fishes that reproduce in, rear in, or migrate through the south Delta, such as threadfin shad, splittail and Chinook salmon from the San Joaquin River. **Geir Aasen** updates annual salvage trends through 2010 for 7 fishes of management concern: juvenile Chinook salmon, juvenile steelhead, juvenile striped bass, delta smelt, longfin smelt, splittail, and threadfin shad. In most cases, low salvage in 2010 was also reflected in low species abundance elsewhere in the estuary. Of particular note was the near record low salvage of threadfin shad and the continued low numbers of splittail in salvage (evidence of some recruitment from the San Joaquin River) even though they were mostly not detected by the trawl surveys.

Lastly, **Jason DuBois, Marty Gingras, and Geir Aasen** describe the extensive array of data sets used by DFG Sturgeon Program to assess white sturgeon abundance and fishery effects, in an effort to better manage the white sturgeon fishery. The species shows periodic recruitment associated with high winter and spring flows. This article is a compilation summary of recent work that can be obtained via the online bibliography cited at the end.

IEP QUARTERLY HIGHLIGHTS

Enhanced Access to Fish Salvage Data

Bob Fujimura (DFG), bfujimura@dfg.ca.gov

The California Department of Fish and Game (DFG) recently provided additional means to access fish salvage information from the Skinner Delta Fish Protective Facility and the Tracy Fish Collection Facility Since the early 1990's, on both weekly and annual bases, DFG staff has been responsible for processing and reporting information on the salvage of fish species of special concern. Greater access to the current information is needed to support rapid adaptive management of water exports and fisheries protection.

A new web page allows users to display salvage estimates for any species requested. Users can query estimated salvage as either densities or total numbers per day. This web page can be visited at http://www.dfg.ca.gov/delta/apps/salvage/Default.aspx. Daily salvage information can be summarized in tabular form for all species and longer time series can be plotted for individual species (Figure 1). To get to this page from the Salvage Monitoring page select 'Salvage/Export Data' or 'Salvage Density Data', click on a date, pick a facility - fish species combination, then an interactive graphic is displayed that will let you plot salvage or density by species, facility and a range of dates. Daily estimates can be downloaded as a CSV data file.

We are also posting a tabular summary of daily delta smelt and longfin smelt salvage during their seasonal salvage period. Daily salvage estimates and running salvage totals are provided as a PDF document along with water flow, turbidity, and water temperature information used in implementation of the USFWS Delta Smelt Biological Opinion. This report can be found at the DFG Region 3, Stockton FTP website at ftp://ftp.dfg.ca.gov/salvage/.

DFG now maintains a web-accessible copy of the master salvage database (Access) containing all the raw data collected from both fish facilities from January 1, 1993 to the present. The database is updated each workday and this information can be found at the previously mentioned FTP site. DBase archive files containing older (since 1957) salvage information can be also found at this location.

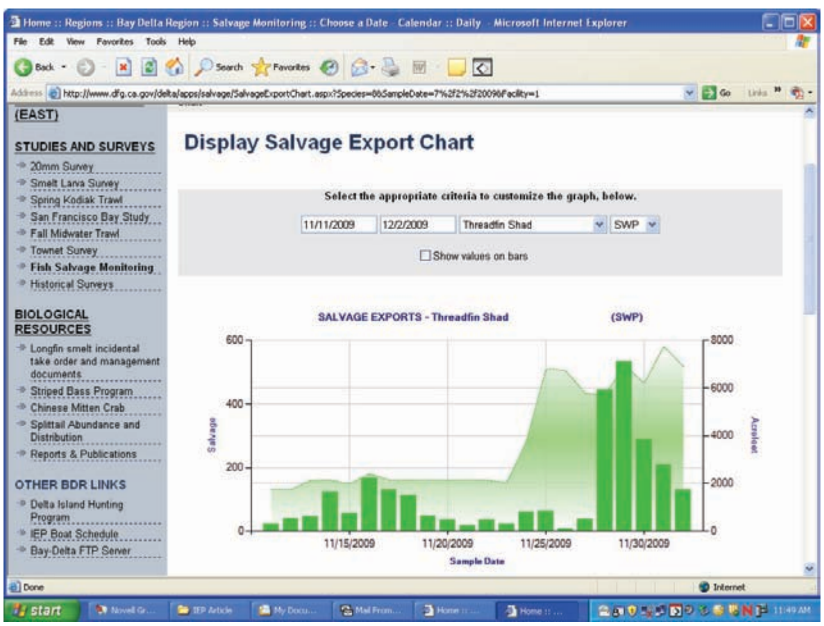

Figure 1 Daily salvage of American shad from the SDFPF and SWP water exports during the period November 11 through December 2, 2009 as reported from the Salvage Monitoring web site

DELTA WATER PROJECT OPERATIONS

January to March 2011

Reza Shahcheraghi and Andy Chu (DWR) , Reza_Shahcheraghi@water.ca.gov

The precipitation pattern in the Delta region, January through March, was reflective of the recorded rainfall at Stockton Fire Station (California Data Exchange Center Code of “SFS”) in Figure 1. By the end of March, the water year type was established as “Below Normal” for Sacramento River Basin and “Wet” for San Joaquin River Basin (see CA Department of Water Resources (DWR) Bulletin 120). The majority of the Delta inflows during these months were a combination of contributions from the upstream reservoir releases and other in–basin accretions originated within Sacramento and San Joaquin Rivers basins.

The Sacramento River flow at Freeport (SACRV) ranged between 460 cms and 2350 cms and the San Joaquin River at Vernalis (SJRV) ranged between 190 cms and 800 cms. Net Delta Outflow Index (NODI) peaked to a high of 6000 cms and receded to 430 cms during the 3-month period (Figure 1). The combined CVP and SWP Projects’ export was as low as zero and peaked as high as 370 cms (Figure 2).

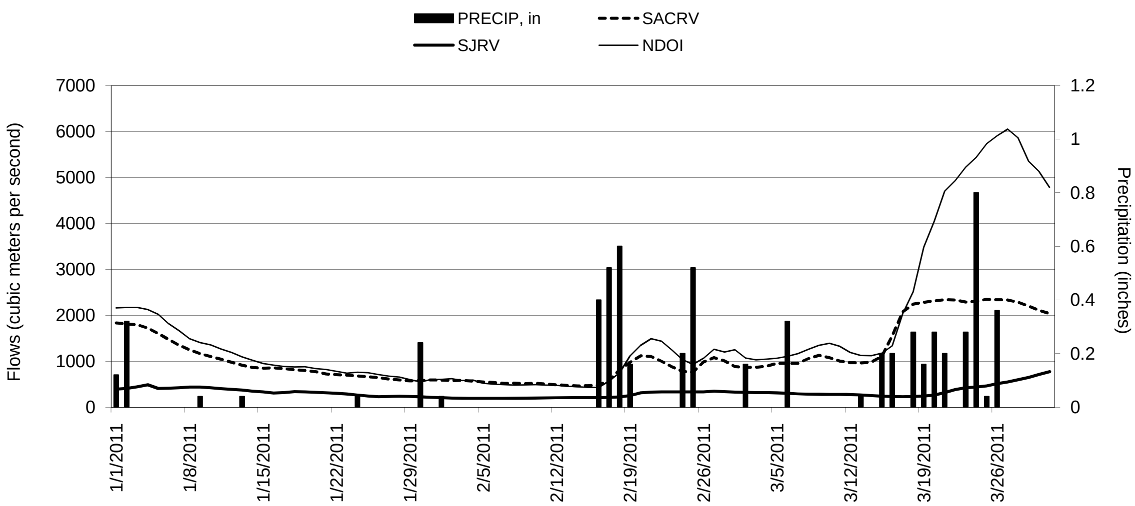

Figure 1 Sacramento River, San Joaquin River, Net Delta Outflow, and Precipitation, January 1 through March31, 2011

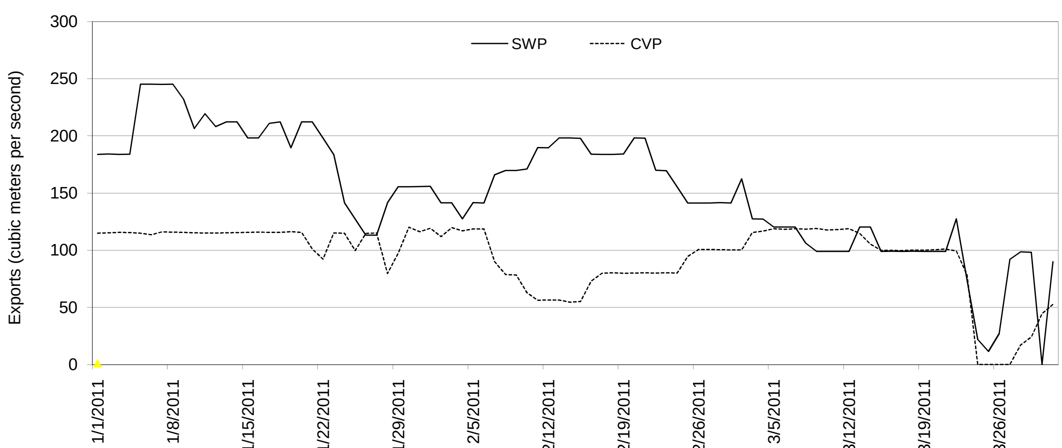

Figure 2 State Water Project and Central Valley Project Exports, January 1 through March31, 2011

STATUS AND TRENDS

DELTA WATER PROJECT OPERATIONS

Reza Shahcheraghi and Andy Chu (DWR), Reza Shahcheragh@water.ca.gov

Water Year 2010 Annual Summary

Precipitation

The precipitation pattern in the Delta region during WY 2010 was reflective of the recorded rainfall at Stockton Fire Station (California Data Exchange Center Code of "SFS") (Figure 1). Water year type listed in the CA Department of Water Resources (DWR) Bulletin 120 is "Below Normal" for Sacramento River Basin and "Above Normal" for San Joaquin River Basin.

Delta inflows

Delta inflows during the year were a combination of contributions from the upstream reservoir releases and other in–basin accretions originated within Sacramento and San Joaquin rivers basins. Sacramento River flow at Freeport (SACRV) ranged between 240 cubic meter per second and 1558 cubic meter per second and the San Joaquin River at Vernalis (SJRV) ranged between 28 cubic meter per second and 170 cubic meter per second (Figure 1).

Delta Export and outflow

Water management within the Delta is regulated by several entities. The State Water Resources Control Board requirements in the Water Rights Decision 1641 (i.e. Export to Inflow Ratio, Minimum Delta Outflow, Habitat Protection Outflow, and etc.) regulate Delta operation, setting export throughout the year. The U. S. Fish and Wildlife Service and National Marin Fisheries Service's Biological Opinions regulate fishery protection and the State Water Project's Incidental Take Permit No. 2081 for longfin smelt and the Vernalis Adaptive Management Program (VAMP) also can further restrict Project's export level and affect the hydrologic parameters in the Delta during the winter and spring months. Lastly, Projects export could also be modified periodically by internal decisions to conduct scheduled maintenances or by forced outages/emergency occurrences.

The combined CVP and SWP Projects' export was as low as 42 cubic meter per second and peaked as high as 320 cubic meter per second (Figure 2). The Delta outflow was as low as 70 cubic meter per second and peaked as high as 1560 cubic meter per second (Figure 1). In addition, the 3-day and 14-day running average of percent inflow diverted indicate that the export to inflow ratio (E/I) was successfully limited to 35% or less during February to June months and 65% or less for the remaining months as stipulated by the State Water Resources Control Board decision 1641 (Figure 3).

Water Year 2010 Annual Totals and Comparison between WY 2006-2010

Water Year 2010 annual totals are listed as follows and also shown in Figure 4.

Sacramento River Flow = 12.67 MAF
San Joaquin River Flow = 1.80 MAF
Net Delta Outflow Index = 9.94 MAF
State Water Project = 2.49 MAF
Central Valley Project = 2.11 MAF
Total SWP and CVP = 4.60 MAF

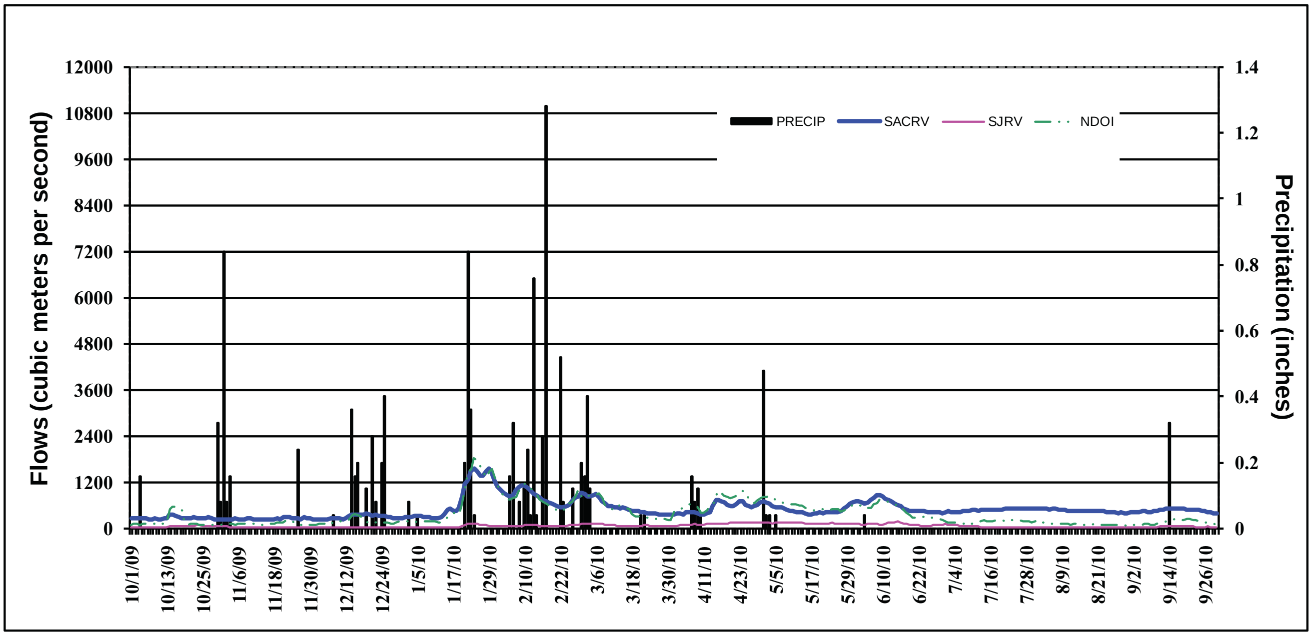

Figure 1 Water year 2010 Sacramento River flow, San Joaquin River flow, net Delta outflow, and precipitation

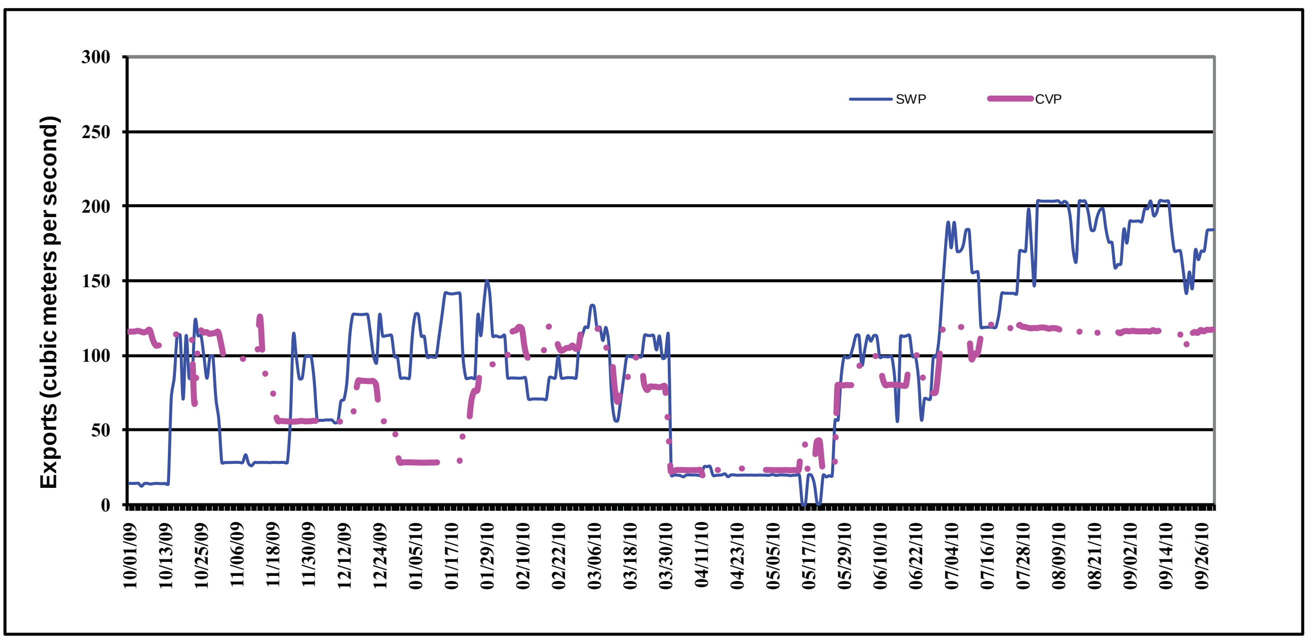

Figure 2 Water year 2010 State Water Project and Central Valley Project exports

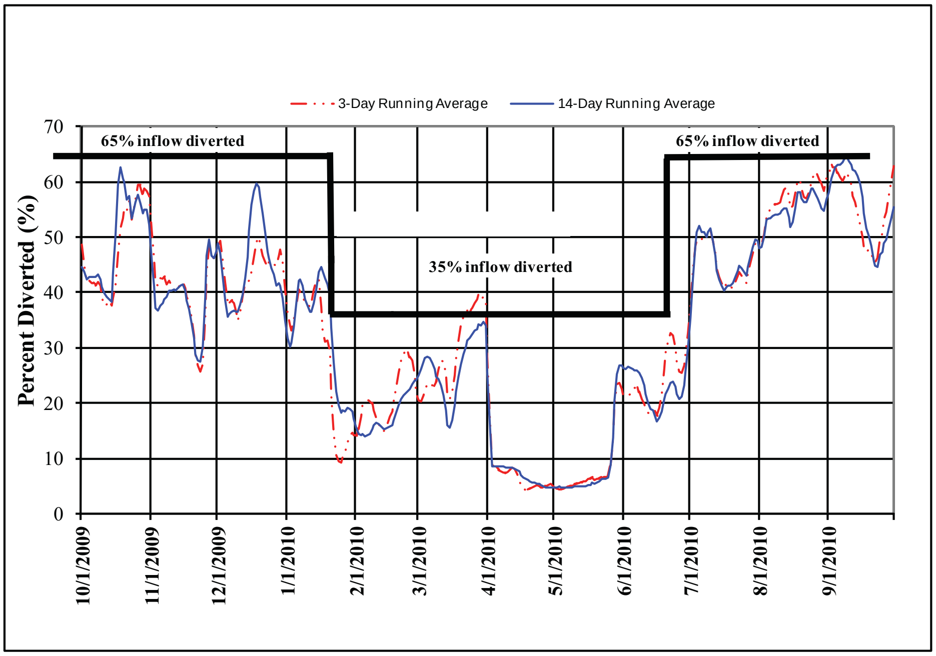

Figure 3 Water year 2010 percent inflow diverted

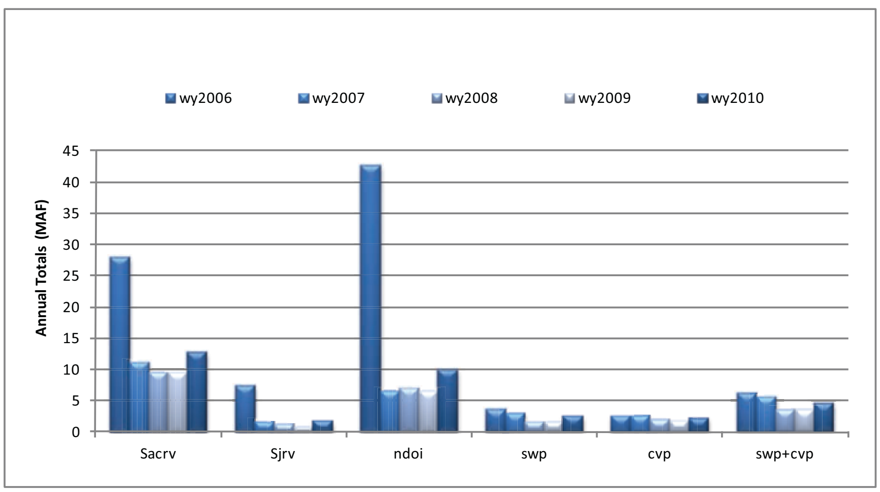

Figure 4 Water years 2006-2010 annual total exports

Monthly Comparison Between Water Years 2006-2010

Sacramento River

The monthly average flows for the Sacramento River in Water Year 2010 were comparable in magnitude or higher than the average monthly flows of the previous four years, except for winter and spring months in Water Year 2006 which was much higher than those of 2010(Figure 5).

San Joaquin River

Similarly the monthly average flows for the San Joaquin River in Water Year 2010 were comparable in magnitude or higher than the average monthly flows of the previous four years, except for winter and spring months in Water Year 2006 (Figure 5).

NDOI

As might be expected given the river flow patterns above, the monthly average Net Delta Outflow Indices for Water Year 2010 were comparable to all previous four years, except for winter and spring months in WY 2006 (Figure 5).

Precipitation

The highest rainfall activity for Water Year 2010 occurred in February (Figure 5). Overall, rainfall in Water Year 2006 was significantly higher than that of any of the other four years.

State Water Project

Normally, the SWP exports are higher during summer and fall months. This was the case for July-September 2010, but not October and November 2009 (water year 2010; Figure 5). Water Year 2006 and 2007 exports were higher than other three years due to water availability (Figure 5).

Central Valley Project

In Water Year 2010, CVP pumping was generally comparable with to the previous four years with the lowest exports occurring in April and May coinciding with the VAMP period (Figure 5).

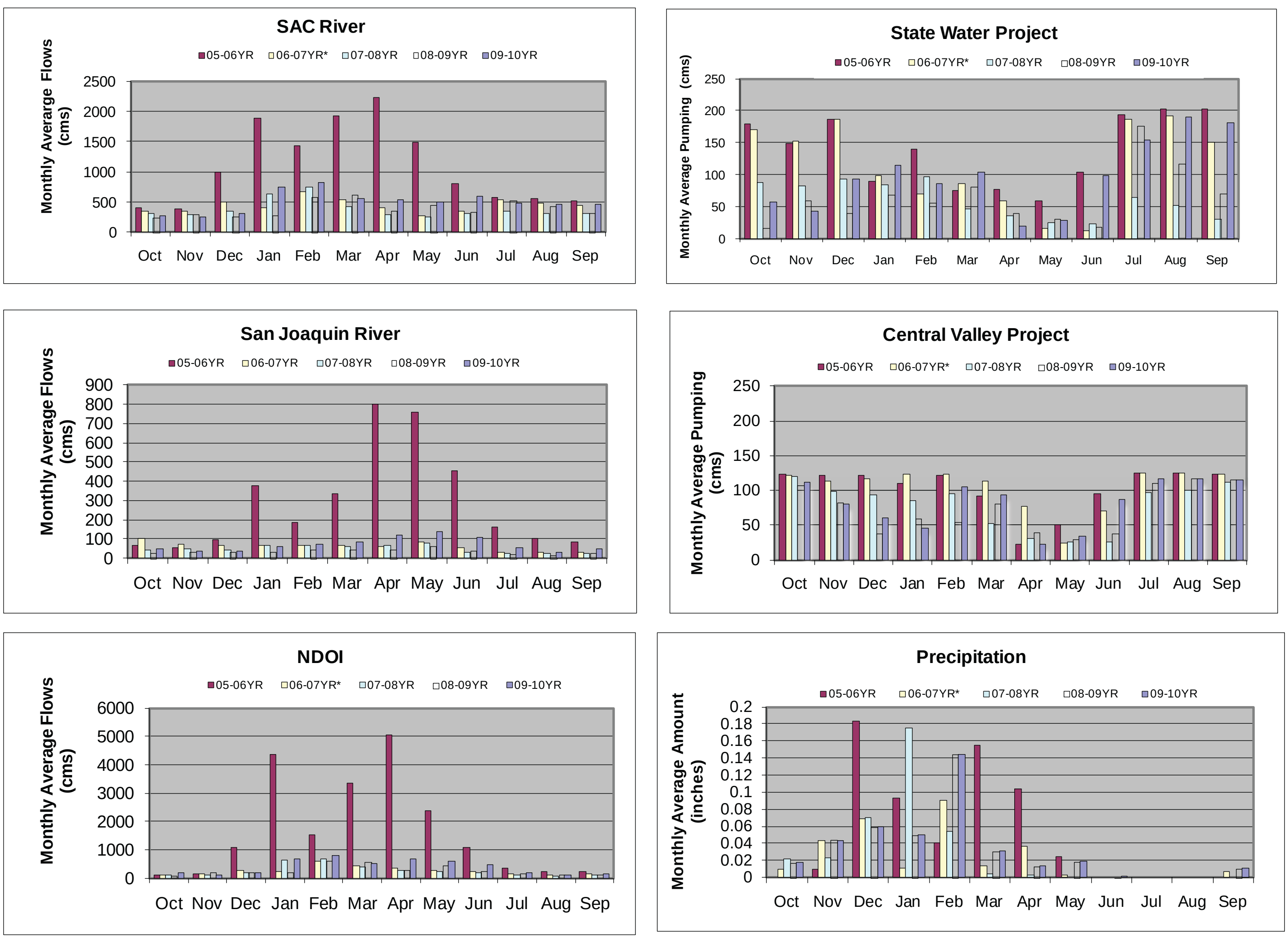

Figure 5 Monthly comparison between water years 2006-2010

Recent Phytoplankton Trends in the Low Salinity Zone

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Introduction

The low salinity zone (LSZ), also called the entrapment zone, of the San Francisco Estuary is where the bottom salinity ranges from 2000 µS/cm to 6000 µS/cm. Historically, it has been considered an important region for estuarine production (Arthur and Ball 1980, Jassby et. al 1995, Lehman 2000). DWR's Environmental Monitoring Program (EMP) began collecting monthly chlorophyll *a* and pheophytin *a* pigment samples in the LSZ in 1996; monthly phytoplankton sampling began in 2008. This report summarizes the LSZ phytoplankton and pigment data from 2008-2010.

Materials and Methods

Phytoplankton

Phytoplankton samples were collected monthly at two stations in the LSZ: EZ2 (where the bottom salinity is 2000 µS/cm) and EZ6 (where the bottom salinity is 6000 µS/cm). Samples were collected using a submersible pump from 1 meter below the water's surface. The samples were stored in 50-milliliter glass bottles. Lugol's solution was added to each sample as a stain and preservative. All samples were kept at room temperature and away from direct sunlight until they were analyzed.

Phytoplankton were identified and enumerated by EcoAnalysts, Inc. according to the Utermöhl microscopic method (Utermöhl 1958) and modified Standard Methods (APHA 1998). An aliquot was placed into a counting chamber and allowed to settle for a minimum of 12 hours. The aliquot volume, normally 10-20 mL, was adjusted according to the algal population density and turbidity of the sample. Aliquots were enumerated at a magnification of 630X using a Leica DMIL inverted microscope. For each settled aliquot, phytoplankton in randomly chosen transects were identified and counted. A minimum of 400 total algal units were counted, with a minimum of 100 algal units of the dominant taxon. For filamentous or colonial taxa, the number of cells per filament or colony was recorded.

Phytoplankton that made up less than 5% of the total at a station over the 3-year period were combined into one category called "Other Phytoplankton." Organism counts for each sample were converted to organisms/mL using the following formula:

Organisms = $(C \times Ac) / (V \times Af \times F)$

where:

Organisms = Number of organisms (#/mL)
C = Count obtained
Ac = Area of cell bottom (mm^2)
Af = Area of each grid field (mm^2)
F = Number of fields examined (#)
V = Volume settled (mL)

This simplifies to:

Organisms = C / cV

where:

cV = Counted volume (mL)
(Note: cV = Ac / (V x Af x F))

Pigment Samples

Chlorophyll *a* and pheophytin *a* samples were collected monthly at EZ2 and EZ6 using a submersible pump from 1 meter below the water's surface. Approximately 500 mL of water was passed through a 47-mm diameter glass-fiber filter with a 1.0 µm pore size at a pressure of 10 inches of mercury. The filters were immediately frozen and transported to Bryte Laboratory for analysis according to the Standard Methods (APHA 1998) spectrophotometric procedure. Samples were processed by mechanically grinding the glass-fiber filters and extracting the phytopigments with acetone. Chlorophyll *a* and pheophytin *a* pigment absorptions were measured with a spectrophotometer before and after acidification of the sample. Concentrations were calculated according to Standard Method's formula (APHA 1998).

The physical location of the stations varied depending on where the bottom salinities of 2000 µS/cm and 6000 µS/cm were found. If the one or both of the target salinities occurred at one of the EMP's fixed stations, data from the fixed station was substituted in the analysis as needed. Missing data (e.g., due to sample loss, or fixed station data could not be substituted) were not included in the analysis.

Results

EZ2

There were peaks of chlorophyll *a* in April 2008, May 2009, and April and May 2010 (Figure 1). Pheophytin *a* closely tracked chlorophyll *a*. Of the 36 chlorophyll *a* samples collected from 2008 to 2010, 33 (91.7%) were below 5 µg/L. Chlorophyll *a* values below 10µg/L are considered food-limiting for zooplankton (Müeller-Solger et al. 2002)

In 2008, phytoplankton peaked in spring and fall (Figure 2A; note the different scales for each graph). Both peaks were mostly the "other phytoplankton" category (primarily nanoflagellates); however, numbers were extremely low (<700 organisms per milliliter). For both peaks chlorophyll *a* values were among the highest recorded for the 3-year period.

In 2009, phytoplankton numbers were much higher overall than 2008 (Figure 2B). Small peaks occurred in February, and in summer; the former was mostly nanoflagellates, the latter were mostly pennate diatoms (primarily *Entomoneis* sp.). Another peak of *Entomoneis* sp. occurred in December. Chlorophyll *a* values were low for all these phytoplankton peaks, suggesting that the phytoplankton were growing very slowly. This may have been due to environmental conditions (e.g. temperature or turbidit) that weren't favorable for a bloom.

Phytoplankton numbers in 2010 were much higher overall when compared to the previous 2 years (Figure 2C). Peaks occurred in spring and fall. The spring peak was mostly centric & pennate diatoms (*Melosira* sp. and *Entomoneis* sp., respectively), along with green algae (*Mougeotia* sp. and *Chlorococcum* sp.). The fall peak was mostly cryptophytes (*Chroomonas* sp. and *Cryptomonas* sp.). The spring peak corresponded with higher chlorophyll *a*, but the fall peak did not. This could be due to unfavorable environmental conditions, or the mixotrophic feeding mode of some cryptophytes (i.e. the ability to feed heterotrophically when unable to photosynthesize efficiently).

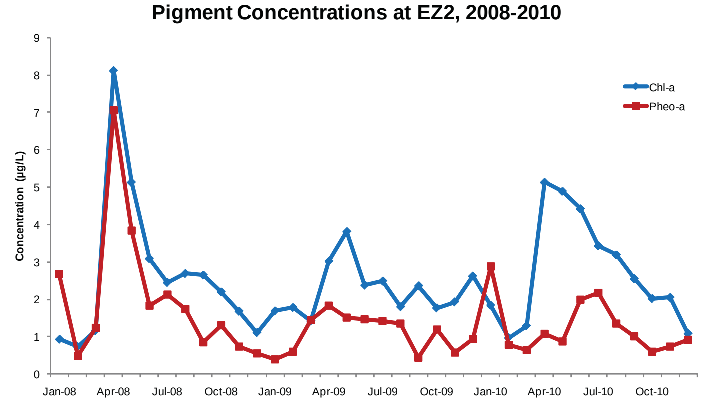

Figure 1 Pigment concentrations at EZ2. Chl-*a* = chlorophyll *a*; Pheo-*a* = pheophytin *a*.

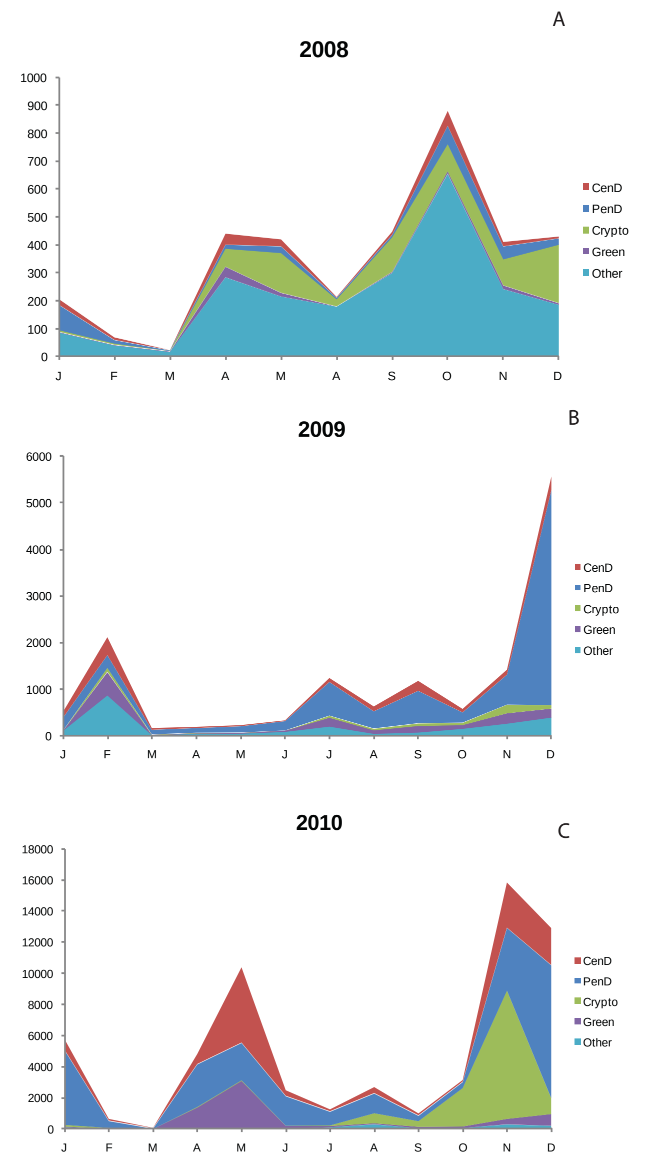

Figure 2 Phytoplankton composition at EZ2 in: A) 2008; B) 2009; C) 2010. X-axis is month; Y-axis is organisms per mL. PenD = pennate diatoms; CenD = centric diatoms; Crypto = cryptophytes; Green = green algae; Other = other phytoplankton.

EZ6

There were chlorophyll *a* peaks in April 2008, May 2009, and May 2010, similar to EZ2 (Figure 3). Also like EZ2, most of the chlorophyll *a* values (33 of 35, or 94.3%) were below 5 µg/L. Pheophytin *a* tracked chlorophyll *a* closely as well.

Phytoplankton in 2008 were similar to EZ2, with peaks of other phytoplankton (mostly nanoflagellates) in spring and fall. (Figure 4A). Numbers were again very low (<700 organisms per milliliter). Chlorophyll *a* was high with the spring peak but not with the fall peak, possibly due to conditions unfavorable to a bloom.

In 2009, a small peak of phytoplankton in August was followed by larger peaks in the fall (Figure 4B). All were due mostly to pennate diatoms (*Entomoneis* sp.). Overall, phytoplankton numbers were higher in 2009 than 2008. Chlorophyll *a* values were low for all peaks, suggesting that environmental conditions were not favorable for a bloom (particularly in December, when light and temperature are more limiting, and residence times are lower. The May 2009 phytoplankton sample was not collected.

Phytoplankton numbers in 2010 were much higher overall than the previous two years (Figure 4C). The community overall was similar to EZ2 as well. Large peaks of centric and pennate diatoms (mostly *Melosira* sp. and *Entomoneis* sp., respectively) occurred in spring, accompanied by a green alga, *Chlorococcum* sp. Chlorophyll *a* was at its highest for the year during the spring bloom. A fall peak of phytoplankton was mostly cryptophytes (*Chroomonas* sp. and *Cryptomonas* sp.) and a dinoflagellate, *Crypthecodinium* sp. Chlorophyll *a* was low during this peak, possibly due to the mixotrophic nature of the cryptophytes, and the fact that *Crypthecodinium* sp. is an obligate heterotroph (i.e. unable to photosynthesize).

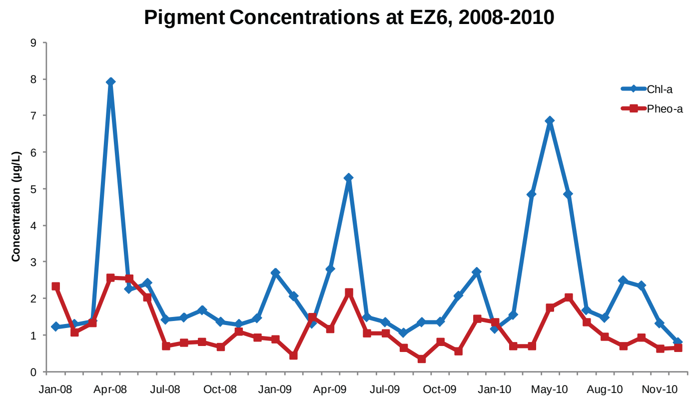

Figure 3 Pigment concentrations at EZ6. Chl-*a* = chlorophyll *a*; Pheo-*a* = pheophytin *a*.

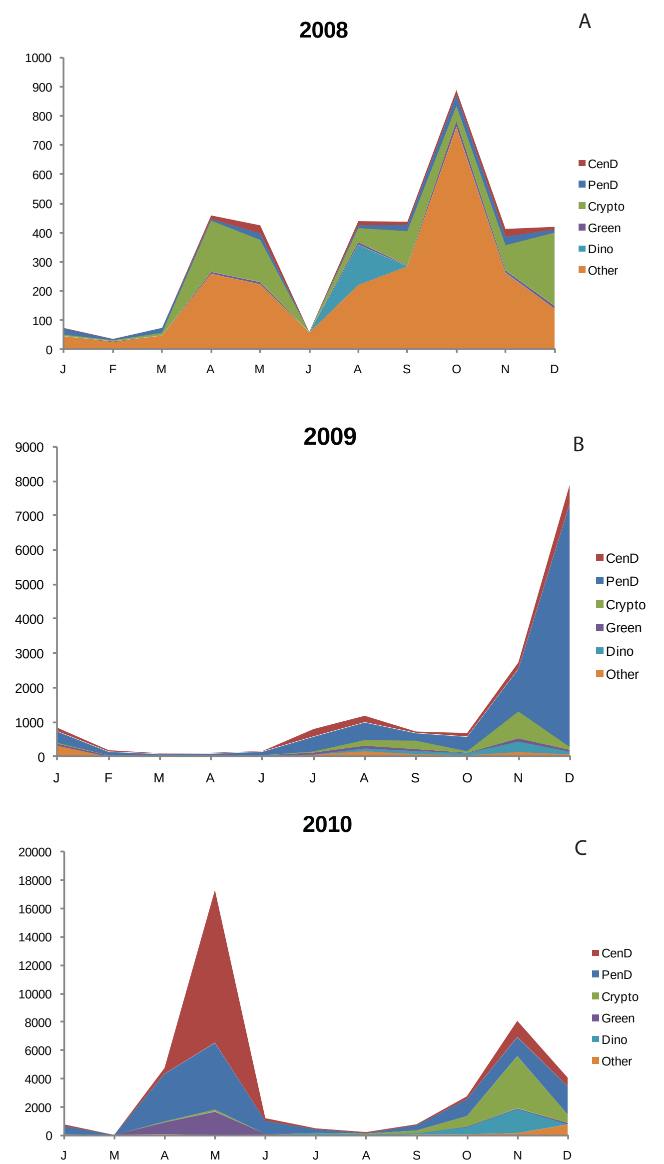

Figure 4 Phytoplankton composition at EZ6 in: A) 2008; B) 2009; C) 2010. X-axis is month; Y-axis is organisms per mL. PenD = pennate diatoms; CenD = centric diatoms; Crypto = cryptophytes; Green = green algae; Other = other phytoplankton.

Summary

The EMP started enumerating phytoplankton in the LSZ in 2008. Chlorophyll *a* and pheophytin *a* monitoring since 2008 showed some peaks at both stations; overall chlorophyll *a* values were low, with over 90% of the samples at both stations below 5 µg/L, which is far below the food-limiting value of 10 micro-grams/L for zooplankton (Müeller-Solger et al. 2002). Pheophytin *a* concentrations generally followed chlorophyll *a* concentrations. The phytoplankton community varied by month and year at both stations, with peaks often caused by just a few taxa. Peaks of phytoplankton numbers (organisms per milliliter) did not always indicate a bloom, as some peaks occurred when chlorophyll *a* values were very low (<3 µg/L). This may be due to environmental conditions (e.g. temperature or light availability) that don't favor a bloom, such as in winter. Or it may be due to the feeding mode of the type of phytoplankton (e.g. mixotrophy in cryptophytes, and obligate heterotrophy for some dinoflagellates).

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Benthic Monitoring, 2010

Heather Fuller (DWR), hlfuller@water.ca.gov

Introduction

The benthic monitoring component of the IEP's Environmental Monitoring Program (EMP) documents changes in the composition, abundance, density and distribution of the macrobenthic biota within the upper San Francisco Estuary. Benthic species are relatively long-lived and respond to changes in physical factors within the system such as freshwater inflows, salinity and substrate composition. As a result, benthic data can provide an indication of physical changes occurring within the estuary. Because operation of the State Water Project can impact the flow characteristics of the estuary and subsequently influence the density and distribution of benthic biota, benthic monitoring is an important component of the EMP. The benthic monitoring data are also used to detect and document the presence of species newly introduced into the upper estuary.

Methods

Benthic monitoring was conducted monthly at 10 sampling sites distributed throughout the major habitat types within the estuary from San Pablo Bay through the Sacramento-San Joaquin Delta (Figure 1). EMP staff collected five bottom grab samples at each station using a Ponar dredge with a sampling area of 0.053 m^2. Four replicate grab samples were used for benthic macrofauna analysis, while the fifth sample was used for sediment analysis. Benthic macrofauna samples were analyzed by Hydrozoology, a private laboratory under contract with the Department of Water Resources. All organisms were identified to the lowest taxon possible and enumerated. Sediment composition analysis was conducted at the Department of Water Resources' Soils and Concrete Laboratory. Field collection methodology and laboratory analysis of benthic macroinvertebrates and sediment composition are described in detail in the benthic metadata found at http://www.water.ca.gov/bdma/meta/benthic.cfm .

Prior to data analyses, individual species counts per grab were expanded to abundance per unit area of a species at a given site and sample date by first averaging the individual counts of each species in the four replicate grabs. The average count was then multiplied by a constant (k) to obtain an average number of individuals per m^2 for a given sampling event. The value of k was computed as follows: $k = 1$ / sample area of the Ponar dredge in m^2. These monthly densities for all phyla were plotted month by month to depict seasonal patterns in benthic communities.

Annual abundances for *Corbula amurensis* at site D41A from 2000-2010 were calculated by first averaging the *Corbula amurensis* counts from the four replicate grabs from each monthly sampling event, then averaging these monthly values to get a yearly averages for each year. The yearly averages were then plotted to depict multi-year patterns in *Corbula amurensis* abundances at D41A.

Results

Seven new species were added to the benthic species list in 2010. These species are not necessarily new to the upper San Francisco Estuary, but they are new to the benthic monitoring component of the EMP. The new species were collected from four stations, but the majority of the new species were collected at D41, the San Pablo Bay station near Pinole Point (Table 1).

Nine phyla were represented in the benthic fauna collected in 2010: Cnidaria (jellyfish, corals, sea anemones and hydrozoans), Platyhelminthes (flatworms), Nermertea (ribbon worms), Nematoda (roundworms), Annelida (segmented worms, leeches), Arthropoda (crabs, shrimp, insects, mites, amphipods, isopods), Mollusca (snails, univalve mollusks, bivalves), Phorinda (phoronids or horseshoe worms) and Chordata (tunicates). Of these phyla, Annelida, Arthropoda and Mollusca made up 93% of all organisms collected in 2010.

Of the 195 benthic species collected in 2010, 10 represented 78% of all organisms collected. These ten species included several amphipods, the Asian clams, several worms and a cumacean (Table 2). Please see Fields and Messer (1999) for descriptions of the habitat requirements, physical attributes and feeding methods of these 10 abundant species.

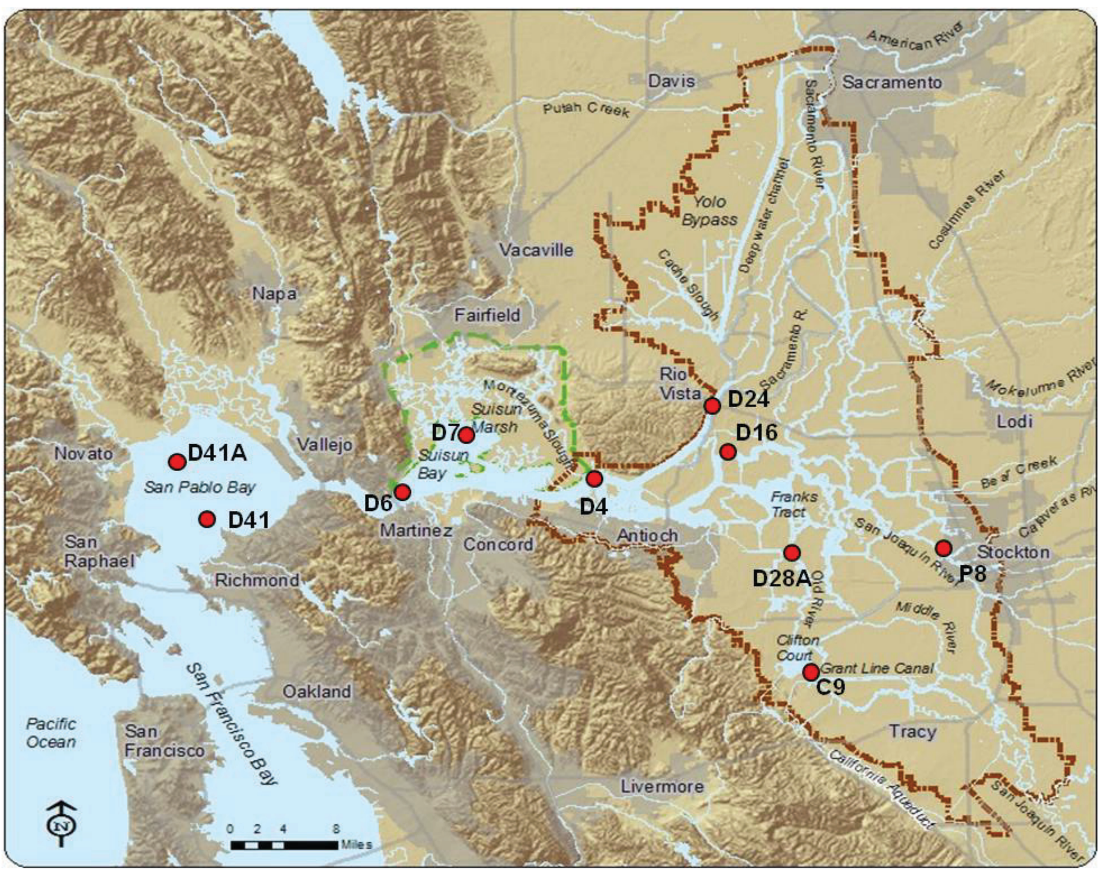

Figure 1 Locations of the Environmental Monitoring Program's benthic monitoring stations

Table 1 Location, collection month, and lowest taxonomic identification of taxa collected for the first time in 2010 by the benthic monitoring component of the Environmental Monitoring Program

Site Name	Location	Month collected	Family	Genus	Species	Common Name
D24	Rio Vista	Feb, May	Chironomidae	Paracladopelma	sp. C	chironomid
D28A	Old River	Oct	Sperchontidae	Sperchon	sp A	water mite
D6	Suisun Bay	Jan	Pholadidae	Zirfaea	pilsbryi	rough piddock (bivalve)
D41	San Pablo Bay	Jan, Feb	Cirratulidae	Caulleriella	sp. A	spionid polychaete
D41	San Pablo Bay	Feb, Apr, July	Cirratulidae	Chaetozone	sp. A	spionid polychaete
D41	San Pablo Bay	Feb, July	Pectinariidae	Pectinaria	californiensis	spionid polychaete
D41	San Pablo Bay	Dec	Pycnogonidae	Pycnogonum	rickettsi	Rickett's sea spider

Table 2 Most abundant species collected by the benthic monitoring component of the Environmental Monitoring Program in 2010

Species	Organism Type	Station(s) at which the species was abundant	Month(s) in which the species was abundant	Total Count for 2010[a]
Corbula amurensis	Asian clam	D6, D7, D41A	May-Nov	36552
Varichaetadrilus angustipenis	Tubificidae worm	D28A, C9, D4	Abundant year round	21498
Americorophium spinicorne	Amphipod	D4	May, June	19159
Ampelisca abdita	Amphipod	D41, D41A	Jan	14251
Gammarus daiberi	Amphipod	D28A, D4	May	13695
Corophium alienense	Amphipod	D7	Nov-Dec	11281
Limnodrilus hoffmeisteri	Tubificidae worm	P8, D4	June-Oct	9937
Corbicula fluminea	Asian clam	D24, D16, D28A, P8, C9, D4	Aug, Sept	9458
Manayunkia speciosa	Sabellidae polychaete worm	D28A, P8	Feb-May	8567
Nippoleucon hinumensis	Cumacean	D6, D7, D41	May, June	7976

[a] Total number of individuals collected by the benthic monitoring program at all stations in all months 2010 (the four replicate grabs collected at each station each month were summed)

North Delta (D24)

D24 is located on the Sacramento River just south of the Rio Vista Bridge (Figure 1). In 2010, the substrate at this station was consistently made up of sand every month. Mollusca was the most abundant phylum at D24 in all months except for March (Figure 2), accounting for 61% of all organisms collected in 2010. Roughly 96% of mollusks found at D24 in 2010 were *Corbicula fluminea.* Annelids (dominated by *Varichaetadrilus angustipenis* and *Limnodrilus hoffmeisteri*) and Arthropods (dominated by *Gammarus daiberi* and *Americorophium stimpsoni*) were also commonly found at D24 in 2010 (Figure 2).

Central Delta (D16, D28A)

The benthic monitoring program sampled at two stations in the central delta. D16 is located in the lower San Joaquin River near Twitchell Island (Figure 1). In 2010, the substrate composition of D16 varied slightly from month to month. In some months it was primarily sand while in others it was a mixture of fines (clay and/or silt) and sand. Substrate type appeared to be associated with organism abundances; organism abundances tended to be much lower in months in which that substrate was primarily sand than in months in which the substrate was a mixture of fines and sand. In the majority of months Arthropoda was the most abundant phylum (48% of all organisms collected). However, in a few months the most abundant phylum was either Mollusca or Annelida (Figure 3). The most abundant arthropods at D16 in 2010 were *Americorophium spinicorne* and *Gammarus daiberi*, the most abundant mollusk was *Corbicula fluminea* and the most abundant annelid was *Variachatadrilus angustipenis*.

D28A is located in Old River near Rancho Del Rio (Figure 1). The substrate at this station generally consisted of a high percentage of organic matter and some sand, though the amount of each varied greatly throughout the year. Annelida and Arthropoda were the two most abundant phyla at D28A in 2010 (Figure 4), with 40% and 36% contribution of total organisms collected respectively. The most common annelid was *Varichaetadrilus angustipenis* (32% of all annelids collected), and the dominant arthropod was the ostracod *Cyprideis sp. A* (58% of all arthropods collected).

South Delta (P8, C9)

The benthic monitoring program sampled at two stations in the southern delta. P8 is located on the San Joaquin River at Buckley Cove (Figure 1). The substrate was generally made up of a mix of sand and organics, though the amount of each varied slightly throughout the year. Annelida was by far the most abundant phyla at this station for all months in 2010 (Figure 5), accounting for 79% of all organisms collected. The dominant annelid was *Manayunkia speciosa*, which accounted for 53% of all organisms collected at P8 in 2010 and was responsible for the peak in total organism abundance in January through June.

C9 is located at the Clifton Court Forebay intake (Figure 1). The substrate at this station was generally some mix of sand and clay, with the amount of each varying depending on the month. Arthropoda was the most abundant phylum in April-July (Figure 6) whereas Annelida was the most abundant phylum in all other months (Figure 6) and accounted for 61% of organisms collected in 2010. *Limnodrilus hoffmeisteri* and *Varichaetadrilus angustipenis* were the dominant annelids at C9 in 2010, while *Americorophium stimpsoni* was the most abundant arthropod (70% of all arthropods collected). These three species drove the increased total organism abundances in spring and summer.

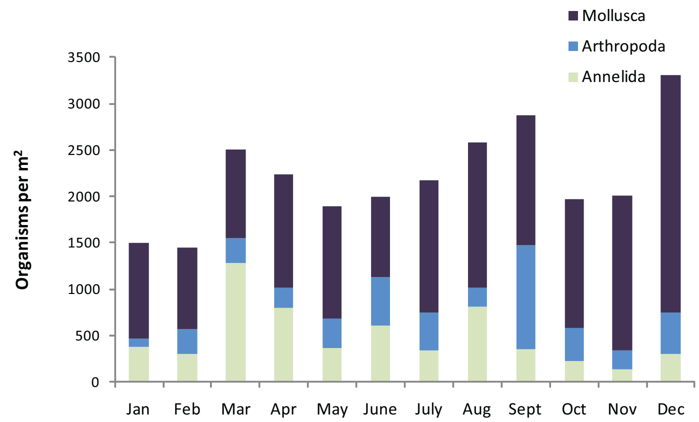

Figure 2 Abundance of benthic organisms, grouped by phyla, collected at station D24 (Rio Vista) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from figure.

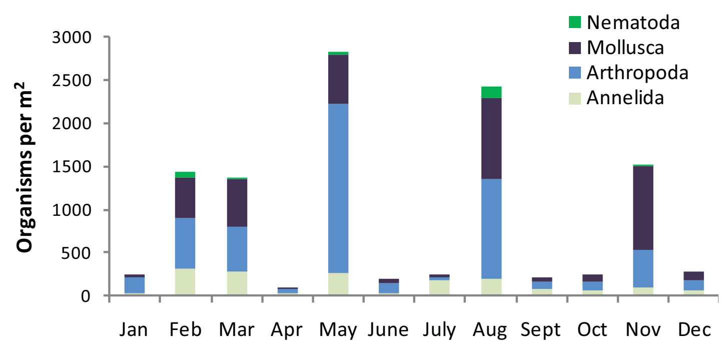

Figure 3 Abundance of benthic organisms, grouped by phyla, collected at station D16 (Twitchell Island) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from figure.

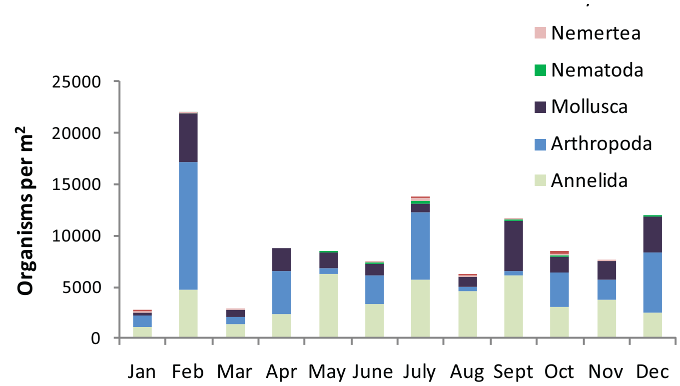

Figure 4 Abundance of benthic organisms, grouped by phyla, collected at station D28A (Old River) by month, 2010.

Confluence (D4)

D4 is located near the confluence of the Sacramento and San Joaquin rivers, just above Point Sacramento (Figure 1). The substrate at this station generally consisted of a mix of organic matter, sand and fines, though the amount of each varied greatly throughout the year. Arthropoda was the most abundant phylum in May-September (Figure 7) and accounted for 58% of all organisms collected. Annelida was the most abundant phylum in all other months (Figure 7), though it should be noted that abundance of annelids was fairly consistent across all months, and accounted for 38% of all organisms collected. *Americorophium spinicorne* was the most abundant arthropod at this station in 2010 (58% of all arthropods collected) while *Varichaetadrilus angustipenis* was the most abundant annelid (70% of all annelids collected).

Suisun Bay (D6 and D7)

The benthic monitoring program sampled at two stations in the Suisun Bay area. D6 is located in Suisun Bay near Martinez (Figure 1). The substrate at D6 was consistently made up of fines (a mix of clay and silt). Mollusca was by far the dominant phylum in all months at this station (Figure 8), accounting for 87% of all organisms collected. Almost all (99.8%) mollusks collected at D6 in 2010 were *Corbula amurensis*.

D7 is located in Grizzly Bay, near Suisun Slough (Figure 1). The substrate at D7 was consistently made up of fines (a mix of clay and silt). Mollusca (almost exclusively *Corbula amurensis*) was the most abundant phylum in May-October and accounted for 44% of organisms collected in 2010 (Figure 9). Arthropoda as the most abundant phylum in all other months (Figure 9) and accounted for 53% of organisms collected. *Corophium alienense* was the dominant arthropod at D7 in 2010, accounting for 75% of arthropods collected.

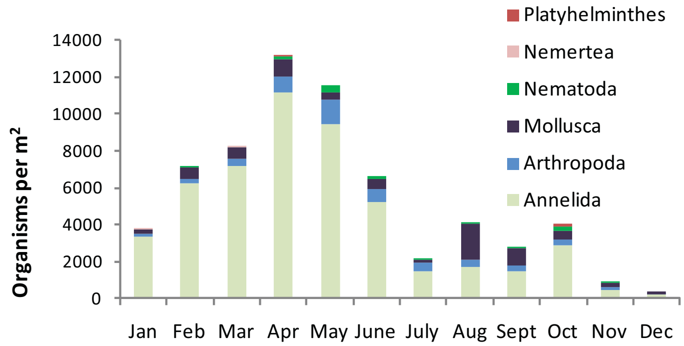

Figure 5 Abundance of benthic organisms, grouped by phyla, collected at station P8 (Buckley Cove) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

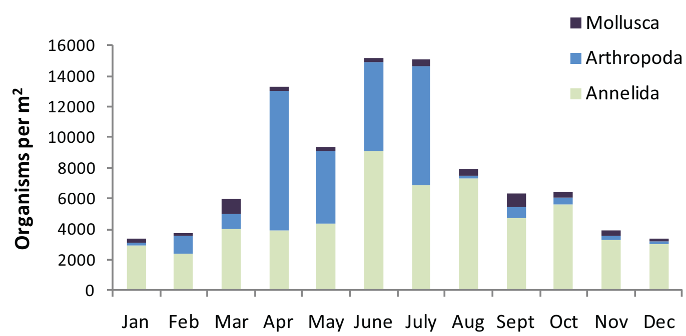

Figure 6 Abundance of benthic organisms, grouped by phyla, collected at station C9 (Clifton Court) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

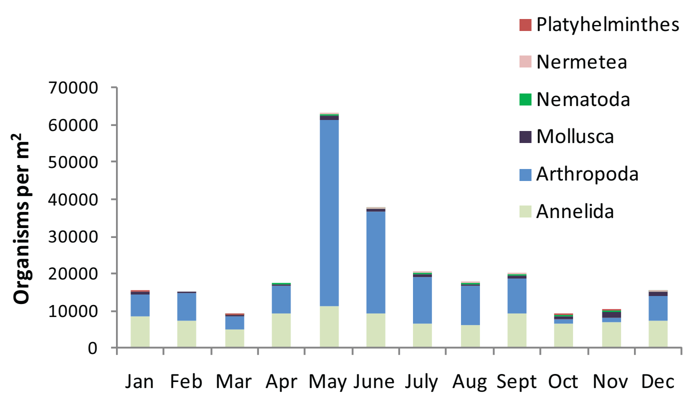

Figure 7 Abundance of benthic organisms, grouped by phyla, collected at station D4 (Confluence) by month, 2010.

San Pablo Bay (D41, D41A)

The benthic monitoring program sampled at two stations in San Pablo Bay. D41A is located near Pinole Point (Figure 1). The substrate at this station was consistently a mix of organics (primarily clamshells), fines and sand. Arthropoda was the most abundant phylum in many months, accounting for 46% of total organisms collected in 2010 (Figure 10). However, in September Phorinda was the dominant phylum due to a very high abundance of one species, *Phoronopsis harmeri* (Figure 10). The most abundant arthropod was *Ampelisca abdita* which accounted for 78% of all arthropods collected in 2010.

D41A is located near the mouth of the Petaluma River (Figure 1). The substrate of this station was made up primarily of fines in all months. The most abundant phylum at this station was Arthropoda in the majority of months (accounting for 63% of organisms collected in 2010), though Mollusca was the most abundant phylum in June through October (Figure 11). The dominant arthropod was *Ampelisca abdita* (72% of arthropods collected), while the dominant mollusk was *Corbula amurensis* (96% of mollusks collected).

The high abundance of *Corbula amurensis* at D41A in 2010 was of particular interest to EMP benthic monitoring staff. *Corbula amurensis* (*Corbula*) is an invasive Asian bivalve that was first discovered in the estuary in 1986 and rapidly became abundant and widespread throughout the brackish and saline regions of the upper estuary. *Corbula* is a voracious filter-feeder and its rise has been linked with declining phytoplankton biomass (Alpine and Cloern 1992; Jassby et al. 2002; Jassby 2006) as well as considerable changes in benthic assemblages (Peterson 2002, Vayssières and Peterson 2010) in the upper estuary. In 2008-2009, *Corbula* was virtually absent from D41A (Figure 12). However, in 2010 the average *Corbula* density for the year (3900 individuals per m^2; Figure 12) was the highest it had been since 2000 (10,600 individuals per m^2). The reasons for the substantial increase in abundance of *Corbula* at D41A in 2010 are not yet known and are currently being investigated.

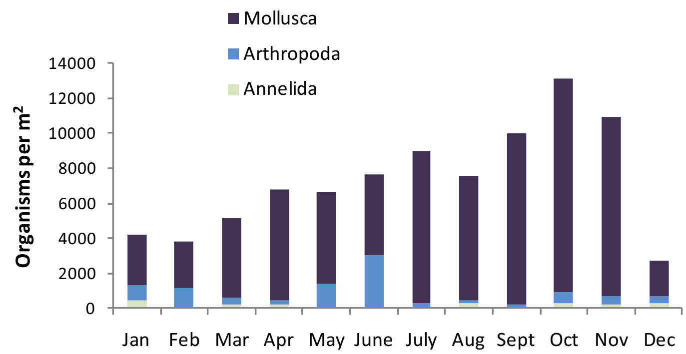

Figure 8 Abundance of benthic organisms, grouped by phyla, collected at station D6 (Suisun Bay) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

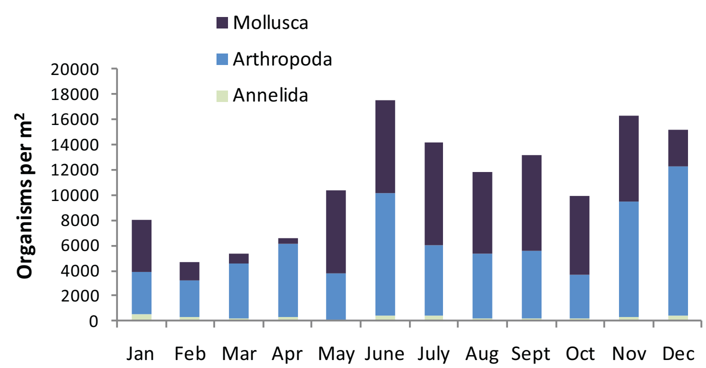

Figure 9 Abundance of benthic organisms, grouped by phyla, collected at station D7 (Grizzly Bay) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted from this figure.

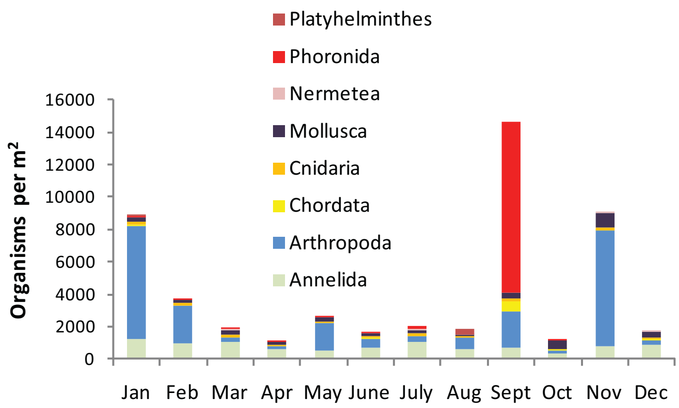

Figure 10 Abundance of benthic organisms, grouped by phyla, collected at station D41 (San Pablo Bay) by month, 2010.

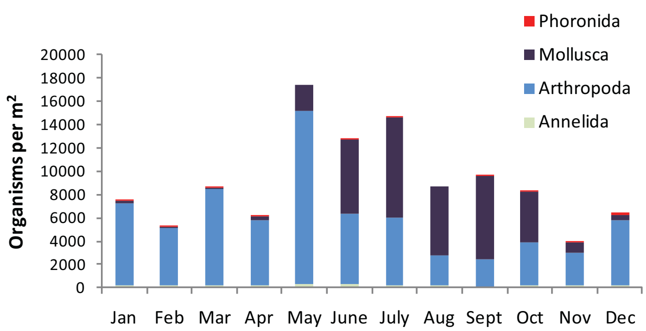

Figure 11 Abundance of benthic organisms, grouped by phyla, collected at station D41A (San Pablo Bay) by month, 2010. Very rare phyla (defined as less than 100 individuals per square meter total for the year) were omitted.

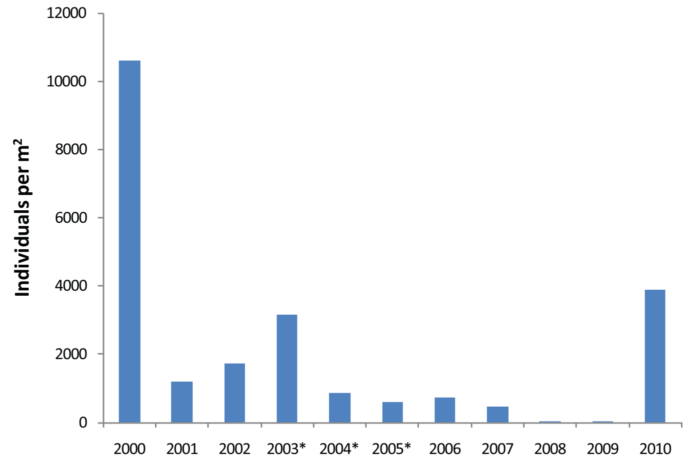

Figure 12 Average yearly abundance of Corbula amurensis collected at Station D41A (San Pablo Bay), 2000-2010. *There were 12 sampling events per year in all years except for 2003, in which there were 10 sampling events, and 2004 and 2005, in which there were 4 sampling events.

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Zooplankton Monitoring 2010

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Introduction

The Zooplankton Study has estimated the abundance of zooplankton taxa in the upper San Francisco Estuary, since 1972 as a means of assessing trends in fish food resources. The study also detects and monitors zooplankton recently introduced to the estuary and determines their effects on native species. Three gear types are used: 1) a pump for sampling microzooplankton <1.0 mm long, including rotifers, copepod nauplii, and adult copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mesozooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods; and 3) a macrozooplankton net for sampling zooplankton 1-20 mm long, including mysid shrimp. Here seasonal abundance indices are presented from 1974 through 2010 for a select group of the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2010, sampling occurred monthly from January through December at 22 stations, including 12 core stations (i.e., stations sampled consistently since study inception in 1972) and 2 floating entrapment zone (EZ) stations located at bottom electrical conductivity of 2 and 6 mS/cm (about 1 and 3 ‰). The study area extends from eastern San Pablo Bay through the Delta and the station map can be viewed at http://www.dfg.ca.gov/delta/data/zooplankton/stations.asp. Indices presented here were calculated using 16 stations: the 12 core stations, the 2 EZ stations, and 2 additional stations sampled consistently since 1974 (Suisun Slough station S42 and Disappointment Slough station MD10). Reports published prior to 2007 used data from 1972 forward that included only the 12 core stations and 2 EZ stations. Since this report utilizes data from 2 additional stations, indices start in 1974 and may be slightly different than those reported prior to 2007. Overall trends remain the same.

Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. January, February, and December were not always sampled historically and therefore were not used for long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter of water (reported as catch-per-unit effort, CPUE) by gear, season, and year for the 16 stations. Relative calanoid copepod abundance for each season of 2010, including winter, which was December 2009 through February 2010, used data from all 22 stations sampled. Similar to the 2004 through 2009 Status and Trends reports, indices reported below were separated by gear type and taxon, whereas pre-2004 reports combined the CB and pump data for each taxon into a single index.

Copepods

Both congeners of the cyclopoid copepod genus *Limnoithona* inhabit the upper estuary: *L. sinensis*, first recorded in 1979, and *L. tetraspina*, first recorded in 1993. In 1993, *L. tetraspina* mostly supplanted the historically common and slightly larger *L. sinensis*, and numerically became the dominant copepod species in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. As an ambush predator that feeds on motile prey (Bouley and Kimmerer 2006), *L. tetraspina* may have benefited from the phytoplankton species composition change described by Brown 2009 from non-motile diatoms to motile flagellates. Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like delta smelt, due to its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006). Both pump and CB net indices are presented here because *L. tetraspina* is not completely retained by the CB net, especially in summer and fall when adults are smaller than in winter and spring. Pump *L. tetraspina* abundance decreased in 2010 from 2009 in all seasons (Figure 1), whereas CB abundance decreased in spring and summer, but increased in fall. In 2010, spring pump abundance was the lowest since 1994, while summer pump abundance was the lowest since 2000 (Figures 1A and 1B). Fall 2010 pump abundance decreased from 2009 and was slightly lower than the fall average from 1999 through 2009 (Figure 1C). *L. tetraspina* was most abundant during late summer and early fall 2010 in the lower Sacramento River, Suisun Marsh, and Suisun Bay. In 2010, peak densities of *L. tetraspina* occurred in July and August in eastern Suisun Bay (52,236 m^{-3}). *L. sinensis* continued to be collected in very low numbers in 2010.

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began, was once a major food for larval and juvenile fishes of many species and adults of planktivores, such as delta smelt and threadfin shad. It is found throughout the upper estuary in every season and is most abundant in salinities less than 6 ‰. *E. affinis* abundance declined in all seasons since monitoring began, with the sharpest downturns during summer and fall of the late-1980s (Figure 2), subsequent to the introductions of the overbite clam, *Corbula amurensis*, and the calanoid copepod *Pseudodiaptomus forbesi*. Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987 abundance has been highest in spring and dropped abruptly in summer, when both *P. forbesi* abundance and *C. amurensis* grazing rates increase. In 2010, *E. affinis* was the fifth most abundant calanoid copepod in the study area across all months. Abundance was highest in spring, when it accounted for 9% of the total calanoid copepod CPUE (Figure 3). *E. affinis* abundance decreased in spring 2010 from 2009, but increased in summer and fall. In 2008, spring abundance was the highest since 1994, but declined in both 2009 and 2010, with 2010 abundance the lowest since monitoring began (Figure 2A). Summer and fall *E. affinis* abundance increased in 2010 and both were among the highest abundances in recent years (Figures 2B and 2C). *E. affinis* was common in Suisun Marsh from January through June, and in the eastern Delta January through May. After a summer decline, densities increased in the eastern Delta from September through November. In Suisun Marsh, densities did not increase from their seasonal low until November and December. In 2010, *E. affinis* abundance peaked in May in eastern Suisun Bay (536 m^{-3}) and Suisun Marsh (371 m^{-3}), and also in the eastern Delta in January (378 m^{-3}) and November (358 m^{-3}).

Pseudodiaptomus forbesi is an introduced freshwater calanoid copepod first detected in the upper estuary in 1988. By 1989, *P. forbesi* summer and fall abundance was comparable to *E. affinis* before its decline (Figure 2). Although *P. forbesi* abundance has declined slightly since its introduction, it remained relatively abundant in summer and fall compared to other copepods. In 2010, *P. forbesi* was the most abundant calanoid copepod in the study area across all months. Relative abundance peaked in summer, when it accounted for 63% of the total calanoid copepod CPUE (Figure 3). Spring abundance has always been highly variable and decreased slightly in 2010 from 2009 (Figure 2A). Summer and fall abundance increased slightly in 2010 from 2009 (Figures 2B and 2C). During summer and fall 2009, *P. forbesi* was common in all regions upstream of Suisun Bay and most abundant in the San Joaquin River and the eastern Delta. The highest density was in July in Frank's Tract in the South Delta, where the CPUE was 5,822 m^{-3}.

Several species of the native calanoid copepod genus *Acartia* are abundant in San Pablo Bay and expand their range into Suisun Bay and the western Delta as salinity increases seasonally and annually. Conversely, their affinity for higher salinities is sufficiently strong that their distribution shifts seaward of the sampling area during high-outflow events, resulting in low seasonal and annual abundance. In 2010, *Acartia* was the second most abundant calanoid copepod in the study area based on mean CPUE across all months. Relative abundance peaked in winter, when *Acartia* accounted for 80% of the total calanoid copepod CPUE (Figure 3). *Acartia* abundance declined in spring and summer 2010 from 2009, for the third year in a row, but increased slightly in fall (Figure 4). The higher spring outflow in 2010 resulted in lower *Acartia* abundance, similar to that seen in the higher outflow springs of 2004 through 2006 (Figure 4A). The lowest summer abundances corresponded with the highest outflow years, and 2010 summer abundance was similar to the most recent higher outflow summers (Figure 4B). By fall 2010, outflow was much lower than during spring and summer, which allowed abundance to increase slightly in 2010 from 2009 (Figure 4C). *Acartia* densities were high throughout the year in San Pablo Bay with a peak in January (4,877 m^{-3}). *Acartia* was also found in Carquinez Strait throughout the year with a peak in January (6,349 m^{-3}).

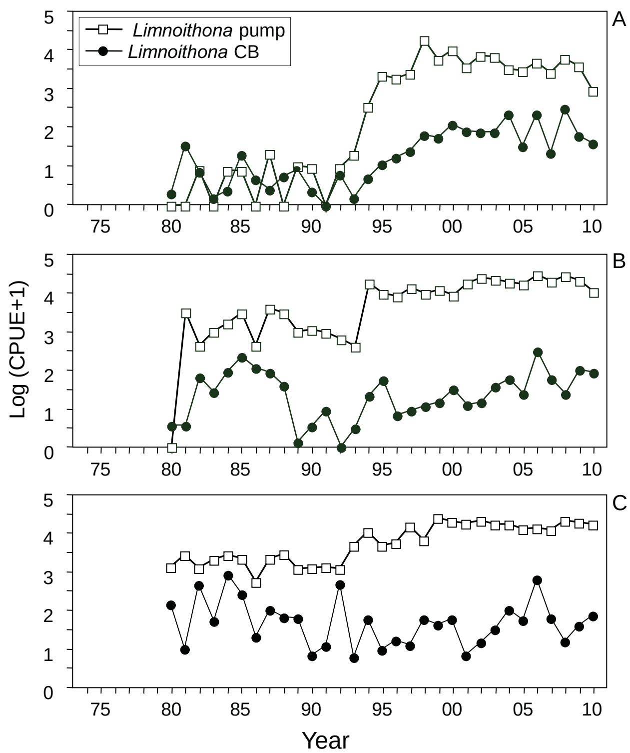

Figure 1 Abundance of Limnoithona tetraspina and L. sinensis combined (Log of mean catch*m^{-3}+1) from the pump and CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

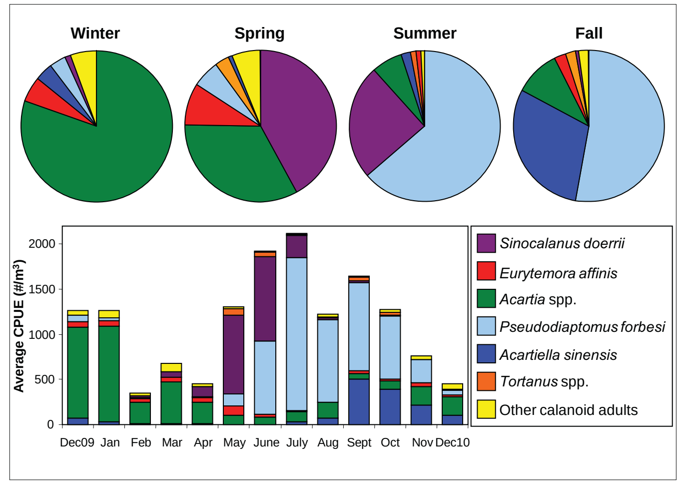

Figure 3 Relative abundance of the most common calanoid copepods (percent mean catch*m^{-3}) from the CB net from all stations by seasons and by months in 2010. Seasonal pie charts include winter (December 2009-February 2010), spring (March-May 2010), summer (June-August 2010), and fall (September-November 2010). Bar graph shows average monthly CPUE of the most common calanoid copepods.

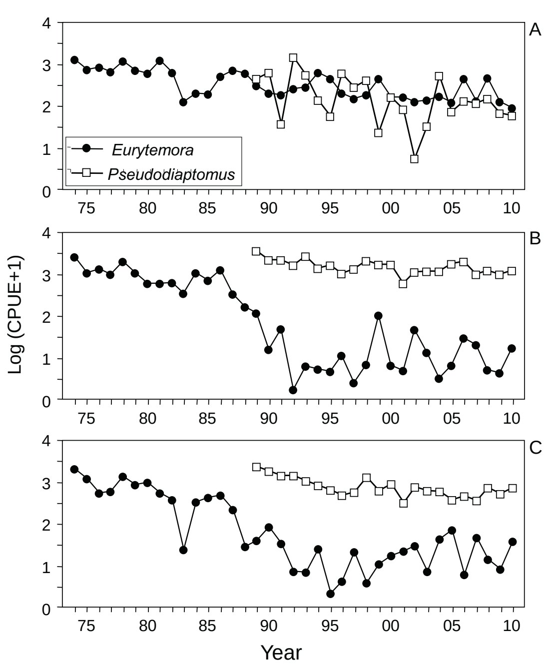

Figure 2 Abundance of Eurytemora affinis and Pseudodiaptomus forbesi (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

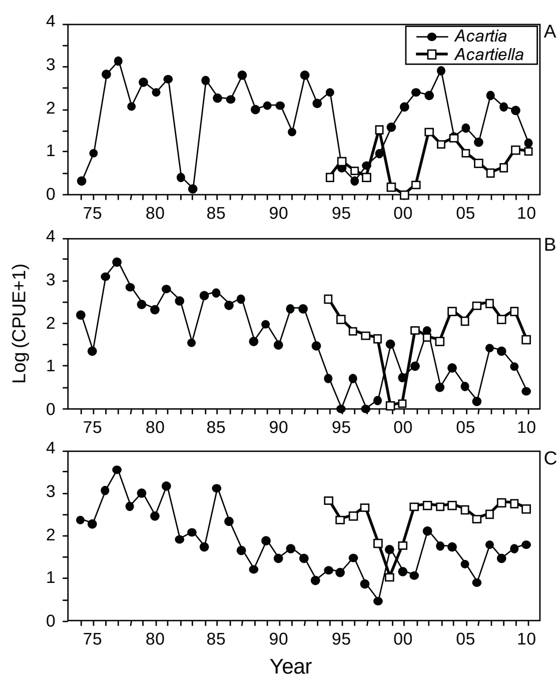

Figure 4 Abundance of Acartia spp. and Acartiella sinensis (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

Acartiella sinensis is an introduced calanoid copepod first recorded in spring 1994 that is most abundant in the entrapment zone during summer and fall. In 2010, *A. sinensis* was the fourth most abundant calanoid copepod in the study area across all months. Relative abundance was highest in fall, when it accounted for 30% of the total calanoid copepod CPUE (Figure 3). In 2010, *A. sinensis* abundance decreased in spring, summer, and fall from 2009 (Figure 4). Spring abundance has always been highly variable, but declined steadily from 2004 through 2007, followed by slight increases in 2008 and 2009, before decreasing slightly in 2010 (Figure 4A). Since 2001, summer abundance rebounded from the record lows of 1999 and 2000, and in 2007, reached the second highest summer abundance since its introduction (Figure 4B). After declining in 2008, summer abundance again increased in 2009 before declining sharply in 2010. Fall abundance has been relatively stable since 2001 and after reaching the third highest in 2009, decreased slightly in 2010 (Figure 4C). In 2010, *A. sinensis* abundance peaked in September in the lower Sacramento River, just downstream of the entrapment zone (2,010 m^{-3}).

The introduced freshwater calanoid copepod *Sinocalanus doerrii* was first recorded in spring 1979. Initially most abundant in summer, *S. doerrii* abundance began to decline during summer and fall in the mid-1980s (Figures 5B and 5C). This downward trend continued through the mid-1990s, followed by modest increases recently. In 2010, *S. doerrii* was the third most abundant calanoid copepod in the study area across all months. Relative abundance peaked in spring, when it accounted for 42% of the total calanoid copepod CPUE (Figure 3). *S. doerrii* abundance increased in 2010 from 2009 in all seasons (Figure 5). Spring abundance, historically more variable than summer or fall abundance, was lowest in 1995 and steadily increased through 2004 before declining again in 2005 and 2006 (Figure 5A). Subsequently, spring abundance increased in 2008, but decreased in 2009 before slightly increasing again in 2010. Summer and fall abundance declined sharply in 2004 and remained low through 2007 (Figures 5B and 5C). In 2010, summer abundance increased sharply from 2009 to the highest level since 1987, while fall abundance increased only slightly from 2009. In 2010, *S. doerrii* was most abundant in May and June in Montezuma Slough in Suisun Marsh (3,147 m^{-3}), and in the lower Sacramento and San Joaquin rivers (1,785 m^{-3}).

Tortanus dextrilobatus is an introduced brackish-water calanoid copepod first recorded in spring 1994. *T. dextrilobatus* is a large carnivorous copepod whose abundance increases in the sampling area as flows decrease and salinities increase during summer and fall. In 2010, *T. dextrilobatus* was the least abundant common calanoid copepod in the study area; relative abundance peaked in summer when it accounted for only 3% of the total calanoid copepod CPUE (Figure 3). *T. dextrilobatus* abundance decreased in spring and summer of 2010 from 2009, but increased in fall (Figure 5). Spring abundance rose steadily from the low in 2006, caused by the extremely high flows, and in 2009 reached the fifth highest spring abundance before dropping sharply in 2010 (Figure 5A). In 2008 and 2009, summer abundance was the highest since *T. dextrilobatus* was introduced, before declining in 2010 (Figure 5B). Fall abundance increased slightly from 2009, and 2010 abundance the highest since 2000 (Figure 5C). In 2010, *T. dextrilobatus* was most abundant in Carquinez Strait, where abundance peaked in June (325 m^{-3}).

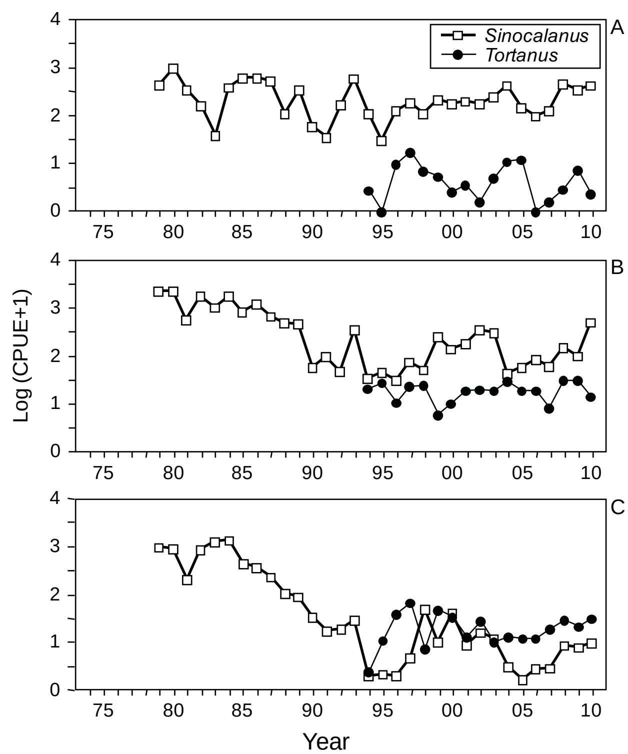

Figure 5 Abundance of Sinocalanus doerrii and Tortanus dextrilobatus (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper estuary. Combined, these native freshwater cladocerans had an overall downward trend since the early 1970s, especially in fall (Figure 6). From 2009 to 2010, abundance remained steady in spring and fall, but increased in summer. In 2010, cladocerans were common throughout the upper estuary upstream of the entrapment zone and were most abundant in the eastern Delta from April through October. Peak densities occurred in the eastern Delta in Disappointment Slough in July (50,335 m^{-3}) and September (40,964 m^{-3}).

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. However, abundance, especially in summer and fall, has experienced long-term declines since the 1970s (Figure 7). Spring abundance, although erratic, has also shown an overall downward trend (Figure 7A). After a peak in spring 2000, abundance declined sharply in 2001, and from 2002 through 2007 there was no catch during spring at any core stations. Low flows in spring 2008 and 2009 resulted in the highest spring abundance since 2000. In 2010, higher outflows resulted in no catch during spring or summer at any stations sampled (Figures 7A and 7B). Summer 2008 abundance was the highest level in 10 years, before decreasing in 2009 and dropping to 0 in 2010 for the first time since monitoring began. Fall 2010 abundance increased slightly from 2009, but was the fourth lowest since monitoring began (Figure 7C). In 2010 *S. bicornis* was only found at 1 station in January in the entrapment zone, and then from Carquinez Strait to the lower Sacramento and San Joaquin rivers from September through November. Peak densities occurred in Montezuma Slough in Suisun Marsh in October (5,070 m^{-3}).

Abundance of all other rotifers, without *S. bicornis*, declined in all seasons from the early 1970s through the 1980s, but stabilized since the early 1990s (Figure 7). In 2010, rotifer abundance increased slightly from 2009 in spring and summer, but decreased in fall. After decreasing to the lowest spring abundance for the study period in 2009, spring abundance increased slightly in 2010 (Figure 7A). Summer abundance increased in 2010 from 2009 for the second year in a row (Figure 7B). Fall abundance decreased in 2010 and was the lowest fall abundance since monitoring began (Figure 7C). Rotifers were common throughout the study area in 2010, with the highest abundance near Stockton in the lower San Joaquin River, where mean CPUE for the year was 67,641 m^{-3} and abundance peaked at 335,352 m^{-3} in August.

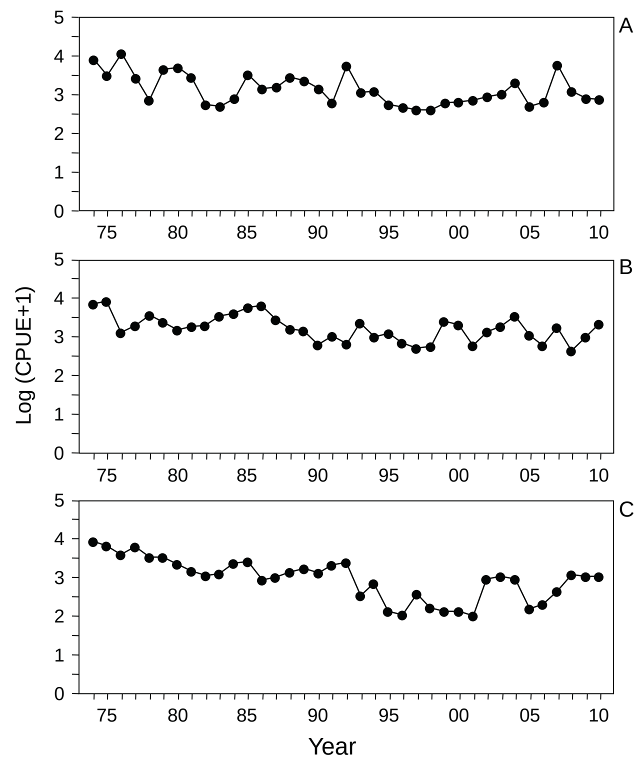

Figure 6 Abundance of Cladocera (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 - 2010.

entrapment zone, which included the lower Sacramento River and eastern Suisun Bay, near the confluence of the Sacramento and San Joaquin rivers. The highest 2010 density occurred in the entrapment zone in June (245 m^{-3}).

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s. In 2010, it was the fourth most abundant mysid in the sampling area across all months for the fourth year in a row. *N. mercedis* is most abundant in spring and summer, and prior to the population crash spring and summer densities averaged more than 50 m^{-3} (Table 1). Since 1994, mean spring abundance has been less than 1 m^{-3}, rendering *N. mercedis* inconsequential as a food source in most open-water areas of the upper estuary. After a record low in 2007, spring 2008 abundance increased slightly, but decreased in 2009 and again in 2010 to the second lowest since monitoring began. Summer abundance has been extremely low since 1997. After decreasing to the lowest summer abundance on record in 2009, summer abundance increased slightly in 2010 to the highest since 1999. No *N. mercedis* were caught during fall at any of the stations sampled from 2005 through 2008. In both fall 2009 and 2010 only 1 *N. mercedis* was caught. Since June 2006, *N. mercedis* has been uncommon throughout the study area with densities less than 1 m^{-3} at most stations. In 2010, *N. mercedis* densities exceeded 1 m^{-3} in June in Suisun Marsh (1.4 m^{-3}) and at 1 station in the lower Sacramento River (1.4 m^{-3}), and in July in the lower San Joaquin River (1.6 m^{-3}).

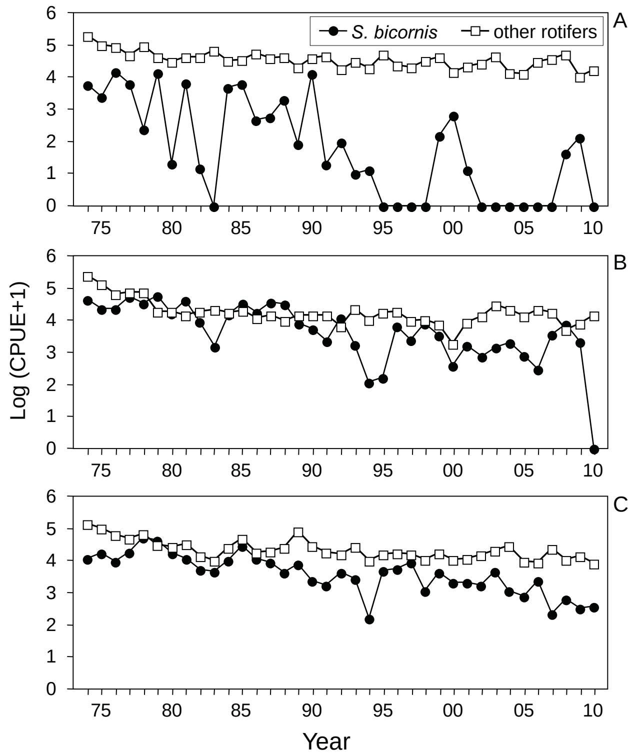

Figure 7 Abundance of Synchaeta bicornis and rotifers excluding *S. bicornis* (Log of mean catch*m^{-3}+1) from the pump in spring (A), summer (B), and fall (C), 1974 - 2010.

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*), an introduced mysid first collected by the study in summer 1993, has been the most abundant mysid in the upper estuary every season since summer 1995 (Table 1). *H. longirostris* is commonly found in densities of more than 10 m^{-3}, and occasionally in densities of more than 100 m^{-3}. Spring *H. longirostris* abundance increased from 1995 to 1998, and fluctuated annually thereafter. Although spring abundance increased in 2010 from the second lowest on record in 2009, it remained below average. Summer abundance had a downward trend since 2003, but in 2010 summer abundance increased sharply and was the highest since 2000. *H. longirostris* fall abundance declined consistently since a local peak in 2004, resulting in record low fall abundances from 2007 through 2009 of less than 1 m^{-3}. In fall, 2010 *H. longirostris* abundance increased from the record lows of the last 3 years, but remained below average. In 2010, *H. longirostris* was most abundant in June and July in the

Table 1 Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net.

Year	*Hyperacanthomysis longirostris*			*Neomysis mercedis*			*Neomysis kadiakensis*			*Alienacanthomysis macropsis*		
	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
1974-1989				54.506	87.293	18.154						
1990				23.458	7.612	0.436						
1991				32.058	18.331	0.489						
1992				4.223	1.989	0.076						
1993			2.470	7.850	22.503	0.008						
1994	0.932	21.604	2.063	0.449	0.733	0.004						
1995	0.437	7.180	4.407	0.590	0.370	0.000				0.000	0.000	0.004
1996	1.636	11.693	4.432	0.541	1.432	0.001	0.032	0.001	0.017	< 0.001	0.000	0.003
1997	6.939	27.630	7.714	0.565	0.063	0.000	0.011	0.011	0.385	0.006	0.000	0.004
1998	18.136	6.015	18.691	0.181	0.238	0.025	0.108	0.041	0.006	0.005	0.000	0.008
1999	3.888	34.697	14.329	0.264	0.288	0.001	0.037	0.007	0.075	0.014	0.000	0.001
2000	23.580	38.453	9.958	0.880	0.136	0.001	0.074	0.165	0.465	0.003	0.000	0.001
2001	4.767	13.441	8.956	0.422	0.052	0.001	0.285	0.351	0.143	0.013	0.001	0.001
2002	10.121	21.224	7.516	0.022	0.069	0.001	0.209	0.254	0.753	0.005	0.000	0.002
2003	4.342	21.307	4.555	0.022	0.046	< 0.001	0.314	0.209	0.166	0.038	0.000	0.003
2004	9.915	13.725	5.044	0.150	0.016	0.002	0.129	0.106	0.170	0.001	0.000	0.001
2005	4.010	16.281	3.265	0.092	0.141	0.000	0.173	0.104	0.077	0.003	0.000	0.004
2006	7.186	14.143	1.967	0.321	0.137	0.000	0.071	0.727	0.051	0.001	0.000	0.001
2007	0.969	8.997	0.575	0.005	0.023	0.000	0.176	0.306	0.122	0.004	< 0.001	0.025
2008	17.696	14.574	0.715	0.063	0.108	0.000	1.359	0.820	0.154	0.027	< 0.001	0.155
2009	0.729	6.303	0.681	0.016	0.013	< 0.001	0.418	0.240	0.128	0.064	0.003	0.096
2010	2.887	25.975	2.045	0.013	0.174	< 0.001	0.177	0.280	0.081	0.090	0.002	0.183
Average:	6.951	17.838	5.521	25.521	39.220	7.879	0.238	0.241	0.186	0.017	< 0.001	0.031

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1996, but was not common until recently (Table 1). From 2001 through 2008, *N. kadiakensis* was the second most abundant mysid in the study area, but in 2009 and 2010 fell to the third most abundant mysid in the study area. In 2010, *N. kadiakensis* abundance decreased in spring and fall, but increased slightly in summer. After reaching a record high in spring 2008, abundance decreased in spring 2009 and again in 2010. In 2010 summer, abundance increased slightly from 2009 and was just above the summer average across years. Fall abundance decreased in 2010 for the second year in a row, and again was below the fall average. In 2010, peak densities occurred in May and June in Suisun Bay (2.3 m^{-3}). Since the late 1990s, *N. kadiakensis* has extended its range into lower salinity water at the confluence of the Sacramento and San Joaquin rivers, leading to the hypothesis that some of the upper-estuary specimens may be a second species, *N. japonica*. To date, no physical characteristics have been published to separate these 2 species.

Alienacanthomysis macropsis is a native brackish-water mysid found most often in San Pablo Bay and Carquinez Strait that was first consistently enumerated by the study in 1995. *A. macropsis* has never been common in the sampling area and therefore indices were not reported until 2007. In 2009 and 2010, *A. macropsis* abundance surpassed *N. kadiakensis* and *A. macropsis* became the second most abundant mysid in the upper estuary across all stations and surveys, although it remained a minor component of the mysid community due to high *H. longirostris* abundance. Spring abundance increased in 2010 for the fourth year in a row and was the highest spring abundance recorded (Table 1). After reaching the highest summer abundance on record in 2009, summer abundance decreased slightly in 2010. Fall 2010 abundance increased from 2009, and was the highest fall abundance recorded. In 2010, *A. macropsis* was most abundant from January through April and again in December in San Pablo Bay and Carquinez Strait; by November and December *A. macropsis* distribution shifted upstream and was most abundant in eastern Suisun Bay. The highest CPUE of 2010 occurred in February in eastern San Pablo Bay and Carquinez Strait where the average abundance was 18 m^{-3}.

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2010 Status and Trends Report for Pelagic Fishes of the Upper San Francisco Estuary

Dave Contreras, Virginia Afentoulis, Kathryn Hieb, Randy Baxter, and Steven Slater (CDFG)[1]

Introduction

The 2010 Status and Trends report includes pelagic fish data from 4 of the Interagency Ecological Program's long-term monitoring surveys in the upper San Francisco Estuary: 1) the Summer Townet Survey (TNS), 2) the Fall Midwater Trawl Survey (FMWT), 3) the Delta Smelt 20mm Survey (20mm Survey), and 4) the U.S. Fish and Wildlife Service (USFWS) Beach Seine Survey (see Honey et al. 2004 for additional information). The most recent abundance indices, long-term abundance trends, and distributional information are presented by species phylogenetically in following sections for American shad (*Alosa sapidissima)*, threadfin shad (*Dorosoma petenense*), delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), wakasagi (*H. nipponensis*), splittail (*Pogonichthys macrolepidotus*) and striped bass (*Morone saxatilis*). Several of these pelagic species that spawn and rear in the upper estuary have undergone severe declines in recent years (Sommer et al. 2007). To date, the abundances of POD fishes persist at very low levels.

Abundance indices and distribution of upper estuary demersal fishes and marine demersal and pelagic fishes will be reported in an upcoming IEP Newsletter.

Methods

Freshwater flow through the estuary positively affects the abundance of many upper estuary fish species (Stevens and Miller 1983, Jassby et al. 1995, Kimmerer 2002). We examined outflow effects by regressing species annual abundance indices on a mean outflow measure derived by grouping flow data from a critical seasonal period in each species' life. Though the actual mechanism(s) for these relationships remain unknown, it is believed that increased outflow enhances abundance by one or more of several mechanisms: 1) increasing low salinity habitat; 2) by dispersing and transporting larvae or juveniles to favorable habitat; 3) by stimulating the food web and increasing food supply; or 4) by reducing predation or other top down effects. Delta outflow data, as daily outflow in cubic feet per second (cfs) at Chipps Island, were acquired from the Department of Water Resources Dayflow database available online at: http://www.water.ca.gov/dayflow/. Daily outflow values were averaged by month, then averaged again for a series of months specific to each fish species representing an important period. In most cases, these outflow means were $\log_{10}$ transformed, and then $\log_{10}$ transformed abundance indices were regressed on the transformed outflow means and plotted. These abundance vs. outflow plots distinguish years leading up to the establishment of *Corbula amurensis* in the estuary (i.e., through 1987), years after establishment (1988 and later) and years after the start of the pelagic organism decline (i.e., POD, i.e., after 2000) to depict how the relationships have changed.

The 20mm Survey monitors larval and juvenile delta smelt distribution and relative abundance throughout its historical spring range, which includes the entire Delta downstream to eastern San Pablo Bay and the Napa River. Surveys have been conducted every other week from early March through early July since 1995, with 9 surveys com-

1. Authorship: Introduction and methods, K. Hieb, S. Slater and Randy Baxter; American and threadfin shad, longfin smelt, and wakasagi, D. Contreras; delta smelt, splittail, and striped bass, V. Afentoulis; and splittail introduction, R. Baxter.

pleted in 2010. Three tows are completed at each of the 48 stations (Figure 1) using a 1,600-µm mesh net (Dege and Brown 2004). Five Napa River stations were added in 1996 and 2 stations each were added in Lindsey Slough, Miner Slough, and the SDWSC in 2008. The survey name is derived from the size (20 mm) at which delta smelt are readily identifiable and counted at the State Water Project and Central Valley Project fish facilities.

The TNS has been conducted annually since 1959, and its data has been used to calculate age-0 striped bass indices for all years except 1966, 1983, 1995 and 2002. In addition, age-0 delta smelt indices have been calculated for the period of record, except for 1966-1968. The TNS currently begins in June and samples 32 historic sites from eastern San Pablo Bay to Rio Vista on the Sacramento River and Stockton on the San Joaquin River (Figure 2). Historically, the number of surveys completed per year ranged from 2 to 5 depending upon how fast striped bass grew past the 38.1 mm length; beginning in 2003, sampling was standardized to 6 surveys per year, starting in early June and running every other week through August. Beginning in 2011, the TNS will add 8 stations in the Cache Slough, Sacramento Deepwater Ship Channel (SDWSC) regions to increase spatial coverage and better detect the range and habitat of delta smelt (Figure 2). At least 2 tows are completed at each station and a third tow is conducted if any fish were caught during the first 2 tows. The annual striped bass index is calculated as an interpolation between the 2 survey indices that bracket when age-0 striped bass reach or surpass a mean 38.1 mm fork length (FL) (Chadwick 1964, Turner and Chadwick 1972). The delta smelt annual index is the average of the first 2 survey abundance indices of each survey year.

The FMWT has sampled annually since 1967, except 1974 and 1979, when no surveys were conducted, and 1976, when sampling was limited and indices were not calculated. The FMWT survey was initiated to determine the relative abundance and distribution of age-0 striped bass in the estuary, and subsequently develop the same information for other upper-estuary pelagic species, including American shad, threadfin shad, delta smelt, longfin smelt, and splittail. The FMWT survey samples 122 stations monthly from September to December in an area ranging from San Pablo Bay to Hood on the Sacramento River, and to Stockton on the San Joaquin River (Figure 3). The index calculation (see Stevens 1977) uses catch data from 100 of the 122 stations; the remaining 22 stations were added over time in 1990, 1991, 2009, and 2010 to enhance our understanding of delta smelt habitat use (Figure 3).

USFWS has conducted beach seine sampling weekly since 1994 at approximately 40 stations in the Delta and the Sacramento and San Joaquin rivers upstream of the Delta (Brandes and McLain 2001, Honey et al. 2004). These 40 stations range from Sherman Lake at the confluence of the Sacramento and San Joaquin rivers upstream to Ord Bend on the Sacramento River, and to just downstream of the Tuolumne River confluence on the San Joaquin River. Catch per haul data from these stations were used to calculate the annual age-0 splittail abundance index. Stations were grouped into 10 regions (5 within the Delta, 3 upstream in the Sacramento River and 2 upstream in the San Joaquin River) and the annual index was calculated as the sum of regional mean catch per seine haul for May and June sampling. Regions were grouped into 3 categories -- the Delta, Sacramento River and San Joaquin River – for graphical presentation and to recognize regional contributions to the overall index.

We used data sets from the TNS and FMWT surveys to describe abundance trends and distribution patterns of upper estuary pelagic fishes listed in the introduction. Two data sets provided only single species indices: the 20mm Survey data for a combined larval and small juvenile delta smelt index and the USFWS beach seine data for age-0 splittail index. Catch-per-unit-effort (CPUE), reported as catch per tow, was consistently used to analyze and report distribution.

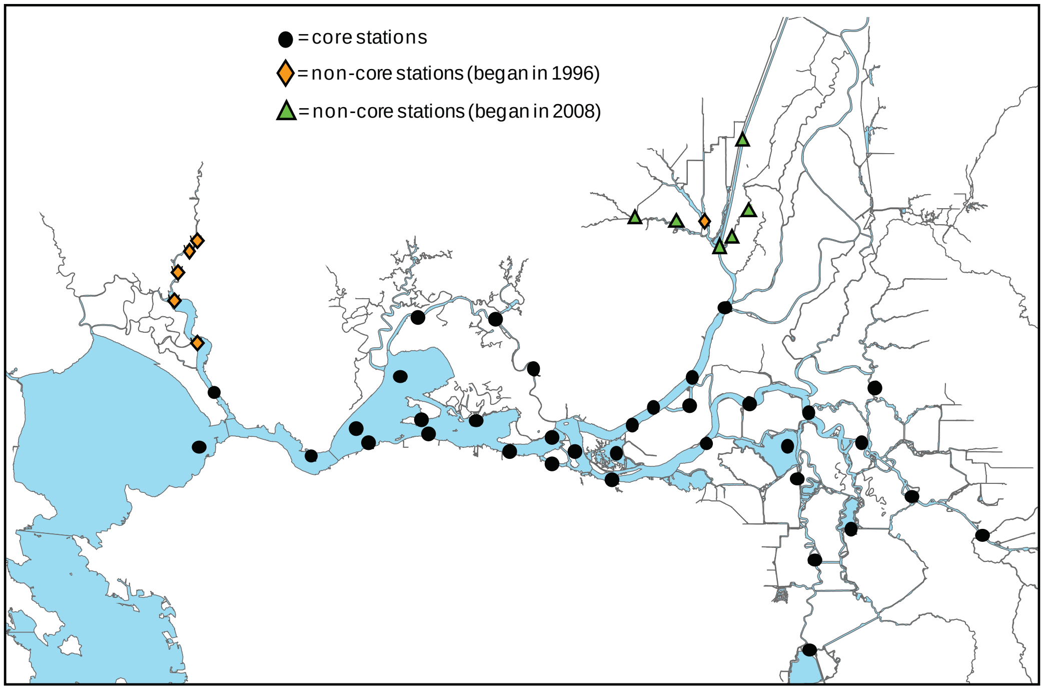

Figure 1 20mm Survey station map.

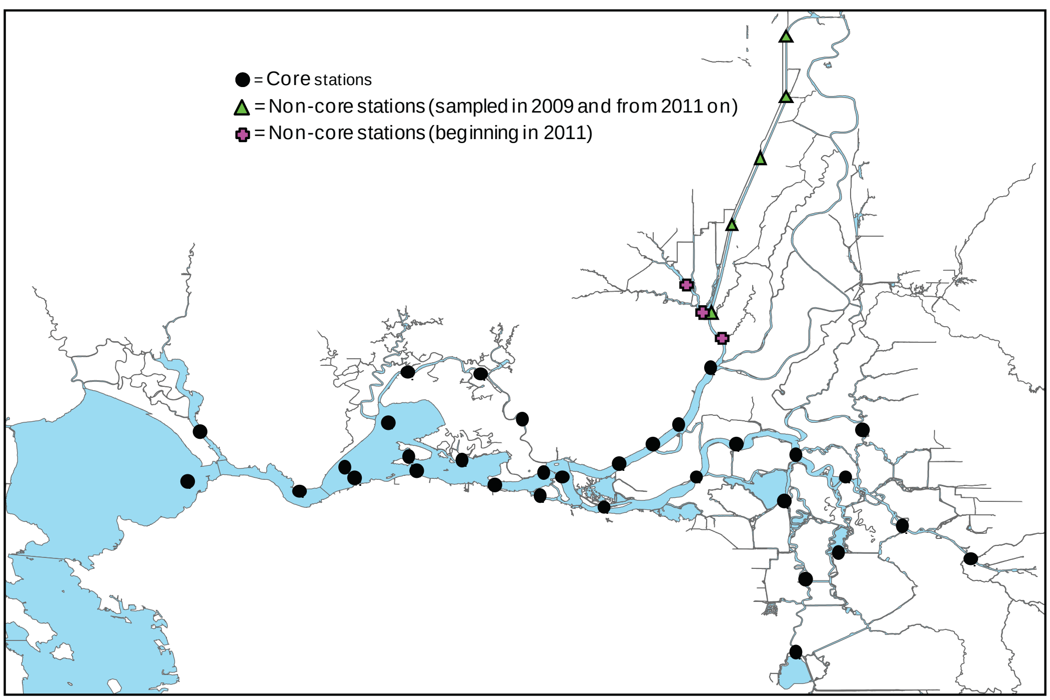

Figure 2 Summer Townet Survey station map

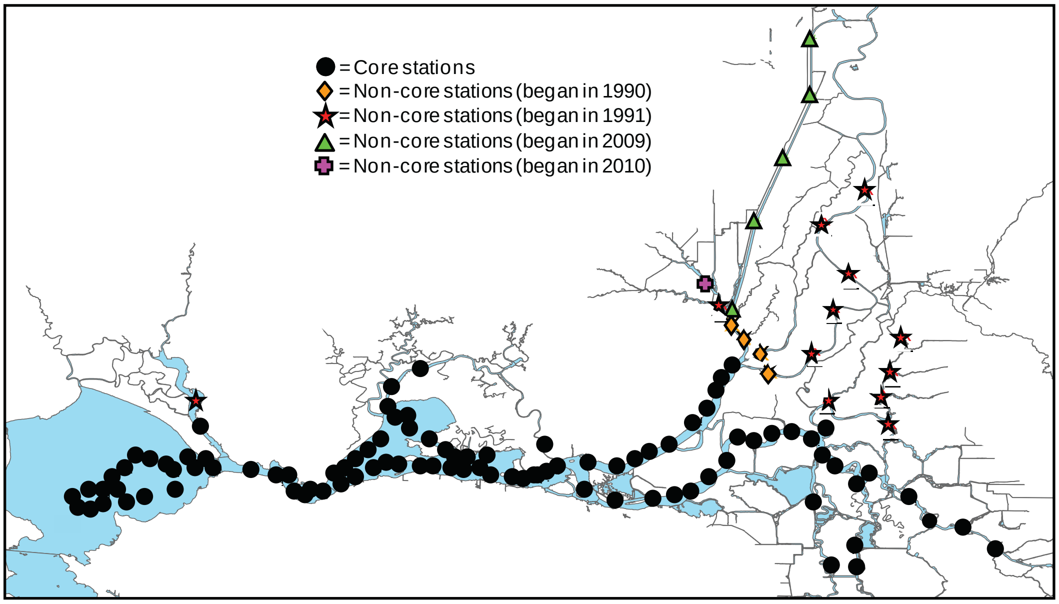

Figure 3 Fall Midwater Trawl Survey station map.

American shad

The American shad was introduced into the Sacramento River in 1871 (Dill and Cordone 1997) and is now found throughout the estuary. This anadromous species spawns in rivers in late spring, rears in fresh water through summer (including the Delta starting in late May), and migrates to the ocean in late summer and fall. It spends approximately 3 to 5 years maturing in the ocean before returning to freshwater to spawn. Most males reach maturity within 3 to 4 years of age, while most females reach maturity within 4 to 5 years of age. Spawning occurs in the Sacramento, Feather, and American rivers from April through June, after which a large percentage of adults die (Stevens 1966). All life stages of American shad are planktivores.

The 2010 FMWT American shad (all ages) index was slightly higher than the 2009 index, and the sixth lowest index on record (Figure 4). With the exception of the record high index occurring in 2003, indices have been below the study-period mean since 1998. American shad were collected in all areas of the upper estuary in 2010, but were most common from the lower Sacramento River downstream through Suisun Bay. The patterns of catches over time reflected out migration as they were most common in the lower Sacramento River in September and October, the SDWSC through Suisun Bay in November, and Suisun Bay through San Pablo Bay in December.

The American shad index increased from 2009 to 2010; however abundance remained relatively low, which may have resulted from the moderately low spring outflow in 2010. American shad abundance has shown a positive correlation with delta outflow during the spring spawning and early rearing period, April through June (Figure 5; Stevens and Miller 1983). For unknown reasons this response was enhanced after the introduction of the overbite clam, *Corbula amurensis*, in the late 1980s (Kimmerer 2002). During the POD years (2001-2010) abundance was more variable and the outflow-abundance relationship became steeper (Figure 5). After 2004, the American shad abundances were lower than expected for the given flows.

Threadfin Shad

Threadfin shad was introduced into reservoirs in the Sacramento-San Joaquin watershed in the late 1950s and quickly became established in the Delta. Although it is found throughout the estuary, it prefers oligohaline to freshwater dead-end sloughs and other low-velocity areas

(Wang 1986). It is planktivorous its entire life, feeding on zooplankton and algae (Holanov and Tash 1978). Threadfin shad may reach maturity at the end of their first year and live up to 4 years. Spawning occurs in late spring and summer and peaks from May to July (Wang 1986).

The 2010 FMWT threadfin shad (all ages) index was 2.8 times the 2009 index (Figure 6) and the second lowest index on record. Since 2002, threadfin shad abundance has been below the study period mean, but showed a slight increasing trend through 2007 before dropping off precipitously. Threadfin shad in September and October were sparsely distributed from Suisun Bay through the lower San Joaquin and Sacramento rivers and Delta, but common in the SDWSC. In November, the distribution contracted to the Sacramento River with a large number collected in the SDWSC (n = 503), and by December fish were distributed in the SDWSC and from the confluence downstream through San Pablo Bay.

Delta smelt

The delta smelt is a small (55-90 mm FL) osmerid endemic to the upper San Francisco Estuary. The delta smelt population declined dramatically in the 1980s and it was listed as a state and federal threatened species in 1993. This species is considered environmentally sensitive because it typically lives for one year, has a limited diet, and resides primarily in the interface between salt and fresh water. In addition, females have low fecundity and produce on average 1,200 to 2,600 eggs (Moyle et al. 1992).

The 2010 20mm Survey delta smelt index was 1.7 times the 2009 index (Figure 7A). The 2010 index is the fourth lowest index on record and consistent with the low indices of the last 4 years. The 20mm Survey began in March with delta smelt larvae present in the lower Sacramento River and Cache Slough. By the end of April, delta smelt catches were highest in the SDWSC and Cache Slough, with some caught in the confluence, Suisun Bay and to a lesser extent in the south Delta. The pattern of larval delta smelt catch in May and June continued to follow the April trend, with the highest catches in the SDWSC and Cache Slough and expansion of catch to Montezuma Slough and Suisun Bay. However, by the end of the survey in July catch of delta smelt juveniles was restricted to the lower Sacramento River, the confluence, and Cache Slough.

The 2010 TNS age-0 delta smelt index was 2.7 times the 2009 index (Figure 7B). The 2010 index is still a small fraction of the majority of indices recorded for the Summer Townet Survey prior to 2005 and ranks as the sixth lowest index during the study period. Delta smelt catch fluctuated over the sampling season, with peaks every other sampling period in mid-June (n=39), mid-July (n=61) and mid-August (n=67) and lower catches in early July, late July, and late August catches that ranged from only 5 to 19 fish. Throughout June, July, and August, delta smelt catch was highest in Suisun Bay, and centered at a Honker Bay station. There was a concurrent low catch of delta smelt in the lower Sacramento River; and only 3 delta smelt were caught elsewhere.

The 2010 FMWT delta smelt index was 1.7 times the 2009 index and was the fifth lowest on record (Figure 7C). In September of 2010, delta smelt were collected from Suisun Bay through the SDWSC and Cache Slough. In October, delta smelt distribution was limited to the lower Sacramento River and SDWSC. No delta smelt were caught in November. In December, delta smelt were collected in Suisun Bay and in the lower Sacramento River and Cache Slough.

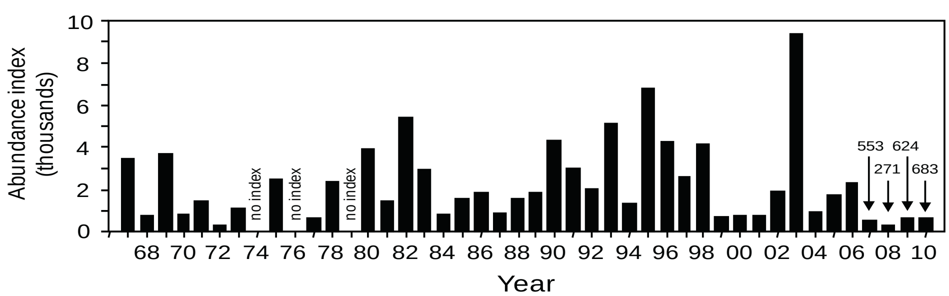

Figure 4 Annual abundance indices of American shad (all sizes) for the Fall Midwater Trawl Survey, September-December.

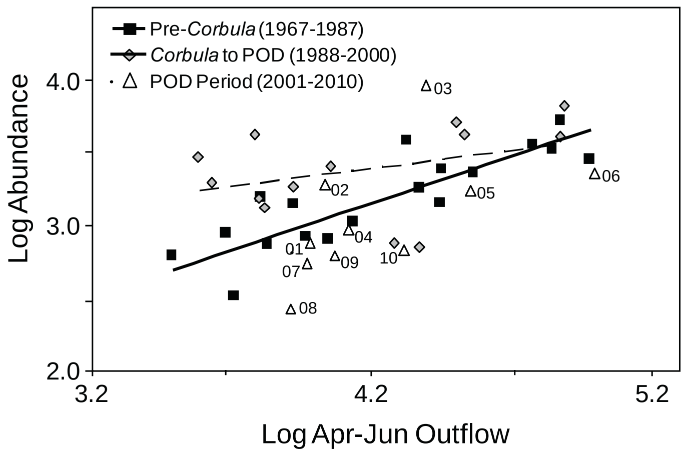

Figure 5 Fall Midwater Trawl Survey American shad (all ages) abundance index vs. average April through June outflow relationships pre-*Corbula amurensis* introduction (1967-1987; solid line), post-*Corbula amurensis* introduction (1988-2000; dashed line), and POD years (2001-2010; dotted line). Abundance and outflow data was $\log_{10}$ transformed.

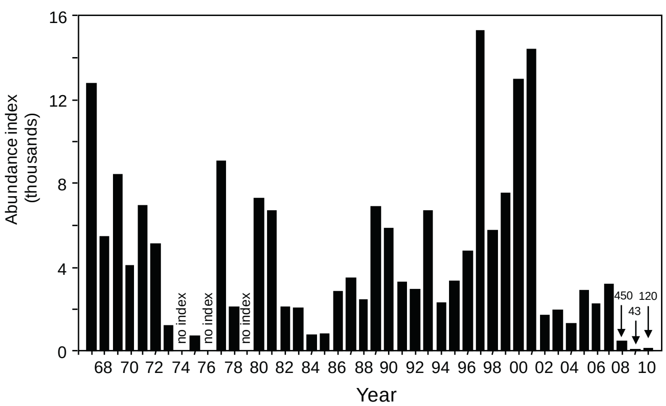

Figure 6 Annual abundance indices of threadfin shad (all sizes) for the Fall Midwater Trawl Survey, September-December.

Longfin smelt

The longfin smelt is a short-lived anadromous species that spawns in freshwater in winter and spring and rears primarily in brackish water. Some age-0 and age-1 fish migrate to the ocean in summer and fall, often returning to the estuary in late fall of the same year. A few longfin smelt mature at the end of their first year and most at the end of their second year, with some living to spawn or spawn again at age-3 (Wang 1986). A strong positive relationship between longfin smelt abundance and winter-spring outflow has long been observed (Stevens and Miller 1983). However, this relationship changed in the late 1980s, after the introduction of the overbite clam, *C. amurensis*. Although the slope of the outflow-abundance relationship did not change appreciably, longfin smelt abundance post-*C. amurensis* declined to a fraction of the pre-*C. amurensis* abundance (Sommer et al. 2007). This decline corresponded with a decline in phytoplankton and zooplankton abundance, which has been attributed to grazing by *C. amurensis* (Kimmerer 2002). A similar downward shift of the longfin smelt outflow-abundance relationship occurred after 2000, during the Pelagic Organism Decline years (Sommer et al. 2007, Fish et al. 2009).

The 2010 FMWT longfin smelt (all ages) index was 2.9 times the 2009 index and tied with the 2004 index as the seventh lowest on record (Figure 8). A few longfin smelt were caught each month from September through November in Suisun Bay, with 1 fish collected in San Pablo Bay in November. Almost all the catch occurred in December. Eight-eight percent of the total FMWT catch (n=85) occurred after water temperatures cooled. They were collected from San Pablo Bay through the Suisun Bay, with 1 fish collected in the lower Sacramento River.

The 2010 FMWT longfin smelt abundance index increased in response to the slightly higher winter/spring outflow than occurred in 2009. The FMWT longfin smelt abundance-outflow relationship shifted downward after the introduction of *C. amurensis* and again in the POD years, 2001-2010 (Figure 9). The 2010 index was slightly above the regression line for the post-*C. amurensis* abundance-outflow relationship. This year's increase in abundance may be attributed, in part, to the relatively strong 2008-year class, the parents of the 2010-year class. Mac Nally et al. (2010) described the FMWT longfin smelt abundance trend as a long-term decline punctuated by abundance increases associated with high outflow periods and they too detected that abundance was most significantly influenced by outflow.

The clam *C. amurensis,* through its affect on the food web, appears to have affected longfin smelt distribution. Longfin smelt distribution in the FMWT shifted towards higher salinity waters after 1989, a few years after *C. amurensis* was established (Figure 10). This suggests that *C. amurensis* displaced longfin smelt through a reduction in food availability, similar to that proposed for the northern anchovy (*Engraulis mordax*) distribution shift downstream reported by Kimmerer (2002). Longfin smelt diet once contained a high proportion of the mysid, *Neomysis mercedis* (Feyrer et al. 2003). The decline of *N. mercedis* also has been attributed to competition for food with *C. amurensis* (Kimmerer and Orsi 1996). One study found that *Neomysis* spp. primarily fed on diatoms, rotifers, and copepods (Siegfried and Kopache 1980), food resources shared with *C. amurensis* (Kimmerer and Orsi 1996). Longfin smelt may have relocated to higher salinity areas to find food sources not impacted by *C. amurensis*.

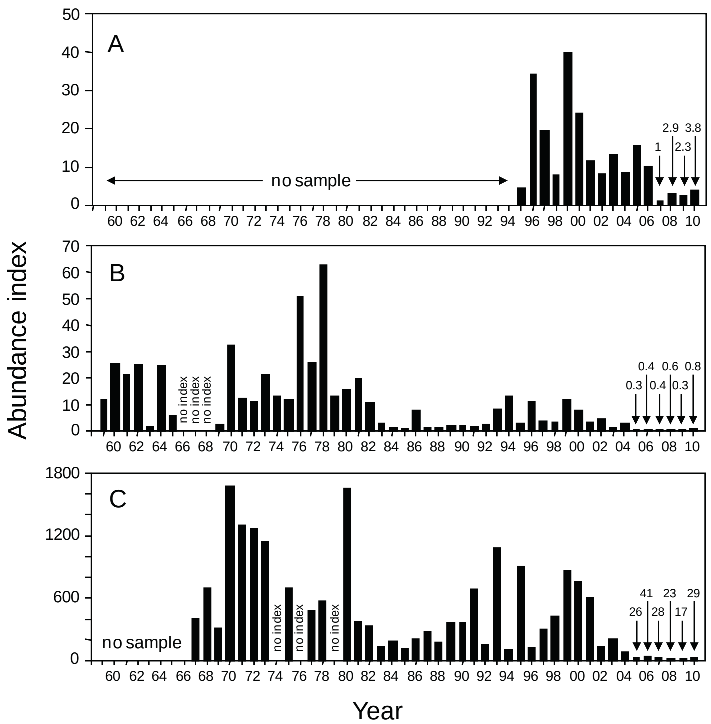

Figure 7 Annual abundance indices of delta smelt: A) 20mm Survey (larvae and juveniles); B) Summer Townet Survey (juveniles); C) Fall Midwater Trawl Survey (sub-adults).

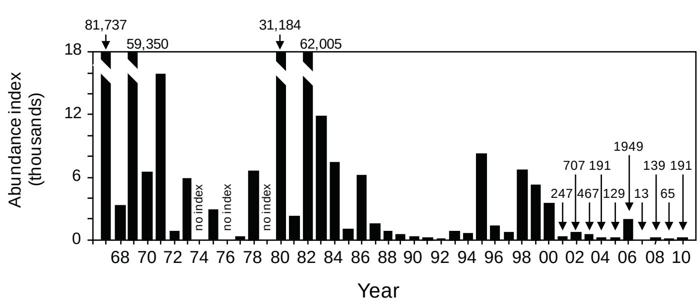

Figure 8 Annual abundance indices of longfin smelt (all sizes) for the Fall Midwater Trawl Survey, September-December.

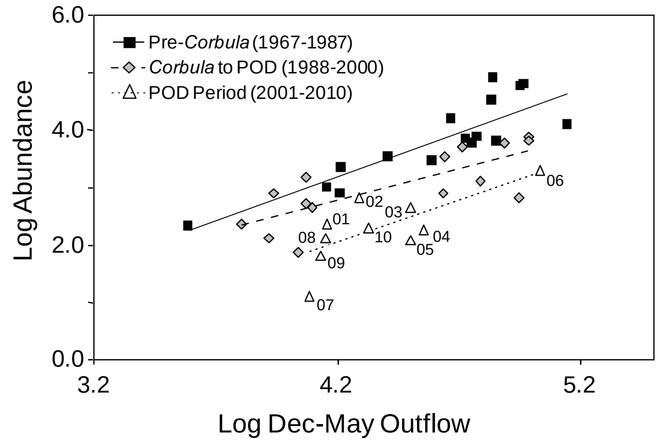

Figure 9 Fall Midwater Trawl Survey longfin smelt (all sizes) abundance index vs. mean December through May outflow relationships pre-*Corbula amurensis* introduction (1967-1987; solid line), post-*Corbula amurensis* introduction (1988-2000; dashed line), and POD years (2001-2010; dotted line). Abundance and outflow data was $\log_{10}$ transformed.

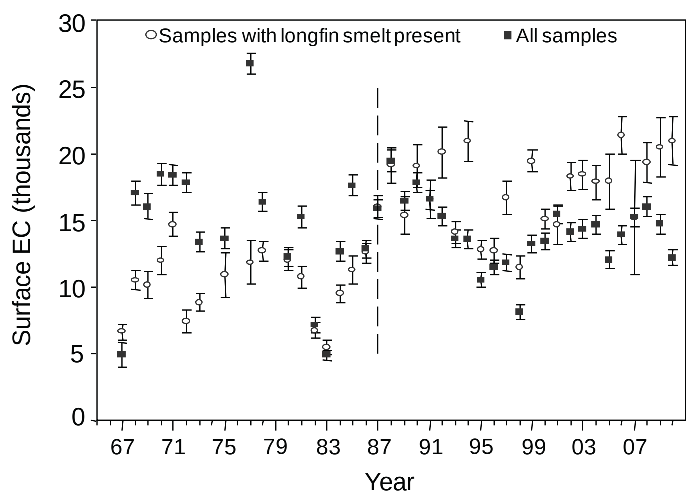

Figure 10 Fall Midwater Trawl Survey mean (±1 SD) surface water electrical conductivity (EC) for samples with longfin smelt present (open circles) and all samples (black squares). Dotted line represents the year *C. amurensis* was discovered.

Wakasagi

The wakasagi was purposely introduced as a bait fish into California lakes and reservoirs from Japan in 1959 (Wales 1962 and Dill and Cordone 1997). Wakasagi were not detected in the San Francisco Estuary until 1990, but may have been introduced as early as 1974 (Moyle et al. 1992). They are generally found in fresh water, but have higher salinity tolerances than delta smelt (Swanson et al. 2000). Wakasagi and delta smelt are typically planktivorous and reach maturity in a year (Moyle et al. 1992). Wakasagi catches are reported here as an update on their abundance and distribution, and to describe its distribution overlap with delta smelt.

Since TNS began in 1959, only 12 wakasagi have been caught at index stations, with 5 of those fish collected in 2009 (Table 1) in Suisun Bay, the confluence, and south Delta. With the addition of SDWSC stations in 2009, wakasagi were collected in the at a much higher frequency than elsewhere in the upper estuary. No wakasagi were caught in 2010 and the SDWSC was not sampled by the TNS.

Few wakasagi have been caught (n=36) by the FMWT survey. Prior to 2009, wakasagi were sporadically collected (n=12) in Grizzly Bay, Montezuma Slough, the lower Sacramento River, and Cache Slough. Similar to TNS in 2009, wakasagi were regularly collected in the SDWSC during 2009 and 2010 sampling (Tables 1 & 2).

For all years, wakasagi were generally found in salinities <0.5 ppt (n=31), but a few were also caught in salinities >7 ppt (n=5), and in temperatures ranging from 9.2ºC to 26.9ºC. The upper temperature observation is a higher temperature than delta smelt can tolerate (Swanson et al., 2000).

Table 1 Summer Townet Survey wakasagi catch per trawl from 1959 to 2010 (regions where no wakasagi were caught removed)

Year	Suisun Bay	Confluence	Lower Sac River	SDWSC	South Delta
1995	0.00	0.02	0.00	no sample	0.00
1996	0.00	0.04	0.03	no sample	0.00
1997	0.00	0.00	0.00	no sample	0.00
1998	0.00	0.00	0.00	no sample	0.01
1999	0.00	0.00	0.00	no sample	0.00
2000	0.00	0.02	0.02	no sample	0.00
2001	0.00	0.00	0.00	no sample	0.00
2002	0.00	0.00	0.00	no sample	0.00
2003	0.00	0.00	0.00	no sample	0.00
2004	0.00	0.00	0.00	no sample	0.00
2005	0.00	0.00	0.00	no sample	0.00
2006	0.00	0.00	0.00	no sample	0.00
2007	0.00	0.00	0.00	no sample	0.00
2008	0.00	0.00	0.00	no sample	0.00
2009	0.04	0.02	0.00	0.40	0.01
2010	0.00	0.00	0.00	no sample	0.00

Table 2 Fall Midwater Trawl Survey wakasagi catch per trawl from 1967 to 2010 (regions where no wakasagi were caught removed)

Year	Suisun Bay	Confluence	Lower Sac River	SDWSC	South Delta
1995	0.00	0.00	0.16	no sample	0.00
1996	0.04	0.00	0.00	no sample	0.00
1997	0.04	0.00	0.00	no sample	0.00
1998	0.00	0.00	0.00	no sample	0.00
1999	0.00	0.00	0.00	no sample	0.00
2000	0.00	0.00	0.16	no sample	0.00
2001	0.00	0.00	0.05	no sample	0.00
2002	0.00	0.00	0.00	no sample	0.00
2003	0.00	0.00	0.00	no sample	0.00
2004	0.00	0.00	0.00	no sample	0.00
2005	0.00	0.00	0.00	no sample	0.00
2006	0.00	0.00	0.00	no sample	0.00
2007	0.00	0.00	0.00	no sample	0.00
2008	0.00	0.00	0.00	no sample	0.00
2009	0.04	0.00	0.05	1.17	0.00
2010	0.00	0.00	0.05	1.60	0.00

Splittail

The splittail is endemic to the San Francisco Estuary and its watershed. Adults migrate upstream from tidal brackish and freshwater habitats during increased river flows from late fall through spring to forage and spawn on inundated floodplains and river margins (Sommer et al. 1997, Moyle et al. 2004). Such migrations are known to occur in the Sacramento, San Joaquin, Cosumnes, Napa and Petaluma rivers, as well as Butte Creek and other small tributaries. Most spawning takes place from March through May. Young disperse downstream as larvae, when river levels drop or as juveniles in late spring and early summer, when backwater and edge-water habitats diminish with reduced flows. Year-class strength is related to the timing and duration of floodplain inundation; moderate to large splittail year classes resulted from inundation periods of 30 days or more in the spring months (Sommer et al. 1997, Moyle et al. 2004).

Age-0 splittail may not be effectively sampled by long-term monitoring surveys employing trawling that requires fishing in open, moderately deep (≥ 2 m) water, because young splittail possess a strong affinity for shallow water. The USFWS Delta Juvenile Fish Monitoring Program conducts an annual beach seine survey and can calculate an abundance index for age-0 splittail. In addition to sampling along the shoreline, this survey samples throughout the Delta and upstream on the Sacramento River to Colusa and on the San Joaquin River almost to the Tuolumne River confluence (see methods), so it is able to detect recruitment upstream in the rivers, which becomes relatively more important as outflow declines.

The 2010 splittail age-0 beach seine index (USFWS data) was 4.2 times the 2009 index and the second highest index (Figure 11A). Seining captured good numbers of age-0 splittail in both the Sacramento and San Joaquin rivers in 2010. Both the highest and lowest abundances (in 2006 and in 2002, respectively) were recorded in the last 10 years. The variability of the age-0 splittail abundances likely reflects the variability in outflows in recent history.

The 2010 FMWT splittail (all ages) index was 0 (Figure 11B). This follows a 2009 index of 1 and 7 prior years of very low indices and reflects reduced use of the water column by splittail even though fall mysid numbers increased in 2010 and were relatively high in the early to mid-2000s (see Hennessy earlier in this issue).

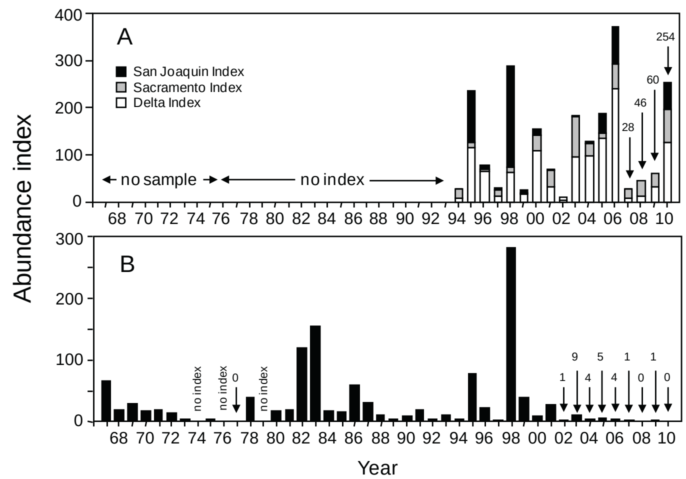

Figure 11 Annual abundance indices of splittail: A) USFWS beach seine (juveniles), May and June; B) Fall Midwater Trawl Survey (all sizes), September-December.

Striped bass

The striped bass is an anadromous fish first introduced to the San Francisco Estuary more than 125 years ago. Adult striped bass forage in the near-shore ocean and coastal bays and migrate up rivers to spawn in spring. Juveniles rear in fresh and brackish waters of the estuary. The population of legal-size fish in the San Francisco Estuary declined during the late 1970's and remained low until 1995 when it inexplicably increased, peaking in 2000 (Figure 12). Since the abundances for year 2004, 2005, and 2007 remain provisional, it is too early to tell if the decline observed after 2000 was interrupted by a brief increase (Figure 12). The most recent estimate is near a record low (Figure 12).

Age-0 striped bass abundance steadily declined after the mid-1980s. TNS and FMWT indices remained generally low in the late 1990s and early 2000s even though the adult population recovered modestly. Although the adult population exhibited a modest recovery, the fraction of females in the spawning run has been very low (~10%) since the early or late 1990s, depending on the data set examined (Jason DuBois, personal communication 2008). Such low female numbers could explain the low juvenile abundance indices. Stevens et al. (1985) hypothesized that low striped bass recruitment was related to: 1) the declining adult population, 2) reduced plankton food supply, 3) loss of large numbers of young striped bass to water diversions, and 4) population-level effects of contaminants.

Based on our understanding of factors controlling striped bass abundance in the estuary, the adult population increases leading to 2000 and in 2004 were unexpected and remain unexplained. Population modeling being conducted by UC Davis researchers in collaboration with IEP Biologists will allow examination of many of these issues.

The 2010 TNS age-0 striped bass 38.1-mm index was 1.9 times the 2009 index and tied with 2003 as the eighth lowest index on record (Figure 13A). Catch of striped bass juveniles peaked at over 300 fish in mid-June, then dropped over the course of the survey resulting in an end of survey late August catch of only 12 fish. In June, the majority of fish caught were in Suisun Bay, with the highest catches in Montezuma Slough. This trend continued throughout July, and August with most fish collected in Suisun Bay and a few fish collected in the confluence and lower Sacramento and San Joaquin rivers. Only 5 age-0 striped bass were caught in the south Delta sampling area during the course of the survey.

The 2010 FMWT age-0 striped bass index decreased to 61% of the 2009 index. This is the lowest index on record and consistent with the low indices seen since 2002 (Figure 13B). They were collected in Suisun Bay in all months. Catches were highest in September and November. In September, age-0 striped bass were caught from San Pablo Bay through the SDWSC, however this wide distribution is represented by merely 10 fish. In October, they were caught in Suisun Bay and SDWSC. By November, age-0 striped bass were caught in Suisun Bay and the south Delta. In December, striped bass were caught from San Pablo Bay through Suisun Bay.

Overall, pelagic fish abundances increased slightly in 2010, but remained at very low levels, striped bass was an exception showing a decline in fall, even though it exhibited a slight increase based on summer sampling by the TNS. These increases were most likely attributed to a slight outflow increase in 2010 compared to recent years (see Delta Water Operations, Water Year 2010 Annual Summary, Shahcheraghi and Chu earlier in this issue). FMWT sampling expanded into the Sacramento Deepwater Ship Channel and Cache Slough in 2009 and 2010 to assess fish use in general and delta smelt use in particular. In both years, FMWT caught delta smelt in low densities in the SDWSC in September and October, and a modest catch of 7 in upper Cache Slough in December 2010. Delta smelt were likely present in November and December of both years (temperatures peaked in September prior to last detection in October), but not always detected due to low densities. These non-index stations also produced relatively high catches of American shad (30-40 per tow on the high end) and threadfin shad (100 to 400+ on the high end), and wakasagi were regularly caught (2-3 per month). Thus, these SDWSC and Cache Slough stations appear to provide year-round habitat for delta smelt and other pelagic fish species. The FMWT will continue sampling these SDWSC and Cache Slough stations in the future and TNS will begin sampling them in 2011.

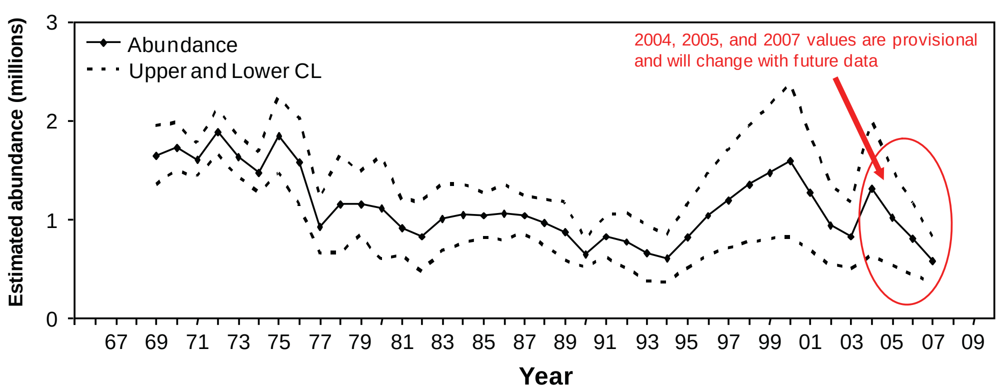

Figure 12 Estimated Abundance of Striped Bass Age ≥ 3 in the San Francisco Estuary from DFG Mark-Recapture Data. Note: values for 1995, 1997, 1999, 2001, and 2006 are mean of estimates from the immediate previous and following year.

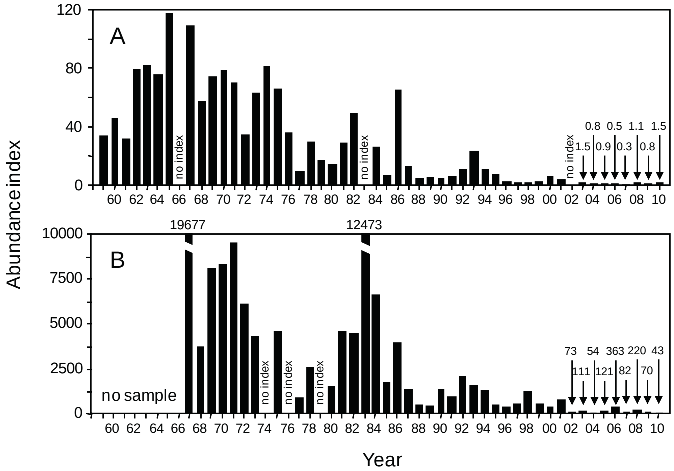

Figure 13 Annual abundance indices of age-0 striped bass: A) TNS 38.1-mm index; B) Fall Midwater Trawl Survey, September-December.

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Notes

Dayflow data from water.ca.gov/dayflow/

Jason DuBois, California Department of Fish and Game, email October 3, 2008.

Juvenile Salmonid Emigration Monitoring in the Sacramento River at Knights Landing

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Introduction

Juvenile anadromous salmonid emigration is being monitored on the Sacramento River near the town of Knights Landing (RM 89.5) for the 15th consecutive year (Snider and Titus, 1998) using paired 8' rotary screw traps anchored in the river. Current monitoring began October 1, 2010 and is scheduled to continue until June 30, 2011. The monitoring is conducted to develop information on timing, composition (race and species), and relative abundance of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*) emigrating from the upper Sacramento River to the Delta. The location at Knights Landing is upstream from the influence of fish produced in the Feather and American Rivers so all salmonids collected are assumed to originate from the upper Sacramento River system. During high flow events, above 23,000 cfs, the Tisdale Weir, located above Knights Landing will spill and divert water into the Sutter Bypass, part of the flood control system for the city of Sacramento. During these events, some juvenile salmonids will emigrate down the bypass and not be seen at the screw traps. The information collected at this sampling site is provided daily to fishery and water managers, providing an early warning for the presence of emigrating threatened and endangered salmon, particularly spring- and winter-run Chinook, heading into the Delta. This warning allows for implementation of management strategies such as closing the Delta Cross Channel gates to keep Sacramento fish out of the central Delta and the reduction of water exports to limit salmonid entrainment. The object of this report is to summarize results from October 1, 2010 to April 22, 2011.

Rotary Screw Trap Operations

For the reporting period of October 1, 2010 through April 22, 2011 monitoring was conducted using paired 8' diameter rotary screw traps (RST) anchored in the Sacramento River (RM 89.5). The RST were fished continuously 24 hours a day, seven days a week and checked daily during the height of the juvenile salmonid emigration. For this reporting period, a total of 6,319 juvenile Chinook salmon were captured. Of these, 5,494 (87.0%) were fall-run, 456 (7.2%) spring-run, 361 (5.7%) winter-run, and 9 (0.1%) late-fall-run (Figure 1a, 1b).

The RST also caught 162 adipose fin-clipped juvenile Chinook salmon which were taken back for removal of a coded wire tag. As of April 22, 2011, the RST captured 48 hatchery (adipose fin-clipped) steelhead and 1, non-ad clipped wild steelhead. All steelhead were released back into the river after processing.

Environmental Parameters

During the sampling period, flows in the Sacramento River ranged from 5,205 cfs on November 16, 2010 and 27,858 cfs on March 25, 2011. Temperature ranged from 48 ºF on February 28, 2011 and 66 ºF on October 5, 2010. Secchi readings were taken during each RST servicing with water clarity ranging from 5' depth on October 21, 2010 and 0.3' depth on March 22, 2011 (Figure 2).

The 2010 / 2011 sampling season so far has seen a very wet year with high flows and the topping of many of the weirs along the Sacramento River above Knights Landing. As in previous years, catch rates seem to correspond with high flow events and the greatest numbers of juvenile salmonids are caught following high flow peaks (Figure 3).

The remainder of the sampling season for the Knights Landing RST should show an increase in the number of captured adipose fin-clipped salmon corresponding with the release of ~13,000,000 hatchery-raised juvenile Chinook salmon from Coleman National Fish Hatchery through the month of April, of which approximately 25% are clipped and have a coded wire tag implanted. The RST at Knights Landing will be in operation until the end of June 2011, or until water temperatures exceed 72 ºF or if there is no capture of juvenile salmonids for several days in a row.

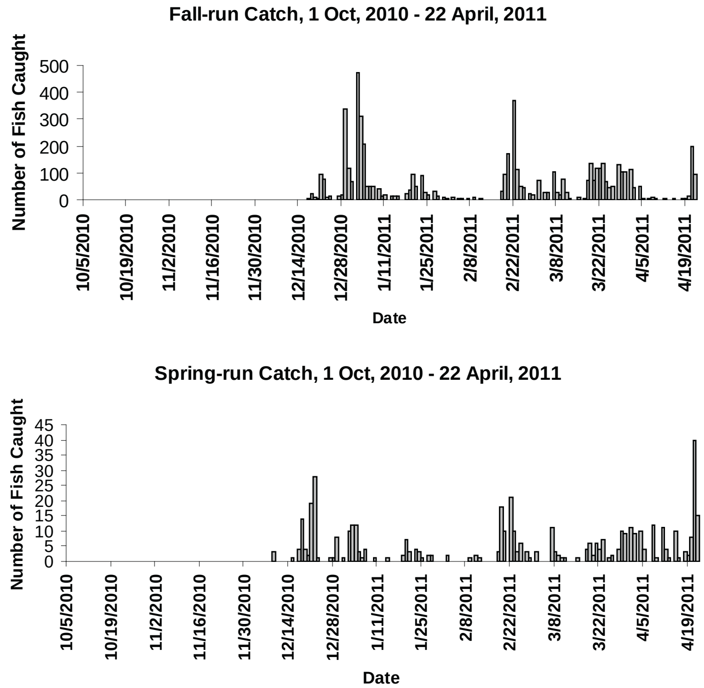

Figure 1a Juvenile Chinook salmon catch by race and timing, Knights Landing RST, Sacramento River, 1 Oct, 2010 - 22 April, 2011.

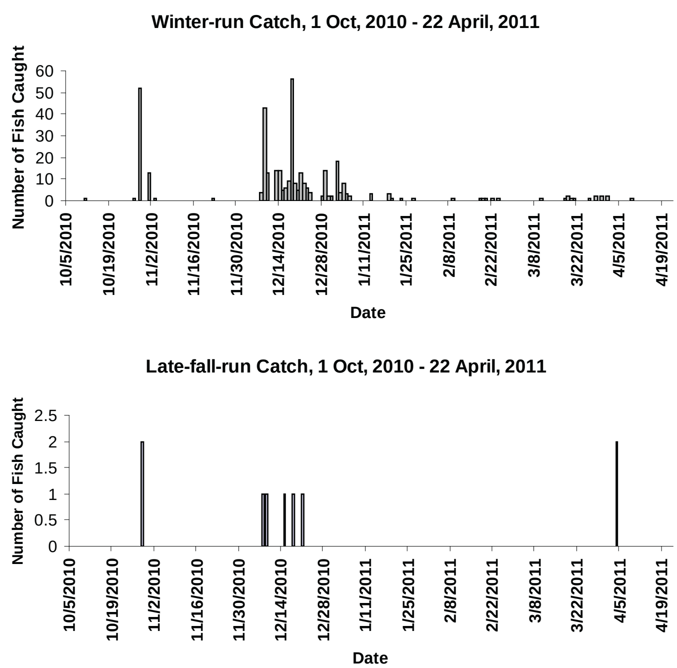

Figure 1b Juvenile Chinook salmon catch by race and timing, Knights Landing RST, Sacramento River, 1 Oct, 2010 - 22 April, 2011.

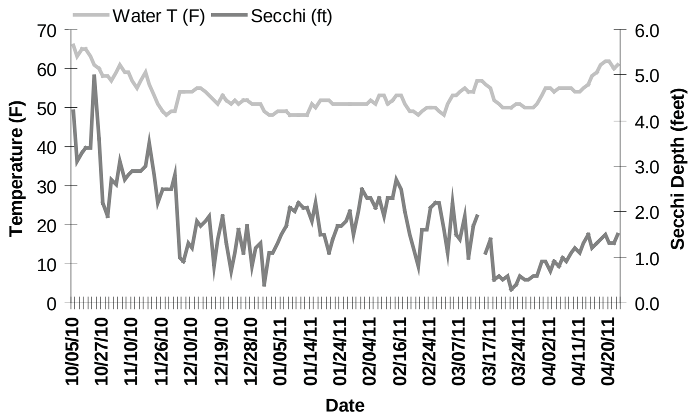

Figure 2 Temperature and water clarity, measured daily at Knights Landing RST, Sacramento River, 1 Oct, 2010 - 22 April, 2011

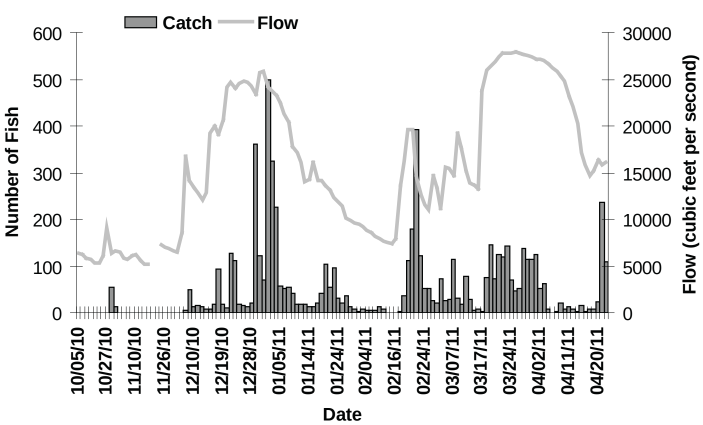

Figure 3 Chinook salmon total catch and Sacramento River flow (cfs) by day, Knights Landing RST, Sacramento River, 1 Oct, 2010 - 22 April, 2011

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Central Valley Chinook Salmon Harvest and Escapement

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California Ocean Harvest

The Pacific Fishery Management Council (PFMC) develops ocean harvest regulations to protect federally listed Central Valley winter- and spring-run Chinook salmon and to meet National Marine Fisheries Service (NMFS) conservation objectives for Sacramento River System and Klamath River fall-run Chinook salmon escapements. The PFMC limited California commercial and recreational ocean fisheries in 2010, and closed the commercial fishery completely in 2008 and 2009, primarily due to the low abundance estimate of Sacramento River fall-run Chinook salmon.

The estimated harvest in California ocean waters was 17,520 Chinook salmon in 2010, the highest since 2007, but 3% of the 40 year average ocean harvest of 576,906 (Figure 1).

California Central Valley Harvest

The California Fish and Game Commission (FGC) develops inland harvest regulations to protect federally listed Central Valley winter- and spring-run Chinook salmon and to meet NMFS conservation objectives for Sacramento River System fall-run Chinook salmon escapements. The FGC limited Central Valley recreational fisheries from 2008 through 2010, due to the low abundance estimate of Sacramento River fall-run Chinook salmon.

The estimated harvest in Central Valley waters was 6,936 Chinook salmon in 2010. The harvest of late-fall-run was 1,687, the harvest of winter run was 0, the harvest of spring run was 43, the harvest of Sacramento fall-run was 5,050, and the harvest of San Joaquin fall-run was 134 Chinook salmon.

California Central Valley Escapement

The California Central Valley contains the Sacramento and San Joaquin river systems. The Sacramento River System is made up of the mainstem Sacramento River and the many tributaries that flow into it. The San Joaquin River also has many tributaries. Each year, escapement estimates are made for Chinook salmon that return to spawn in natural areas and for those that return to hatcheries within these river systems. These estimates are in addition to the inland harvest estimates.

In 2010, the escapement estimate for Chinook salmon returning to hatcheries and natural areas of California's Central Valley was 178,464 fish, the highest since 2006, but 58% of the 40 year average of 308,297 (Figure 2). The late-fall-run escapement was 9,895, the winter-run escapement was 1,596, the spring-run escapement was 3,792, and the fall-run escapement was 163,181 Chinook salmon.

Late-fall-run Escapement to the Sacramento River System

The estimated escapement of late-fall-run Chinook salmon to the Sacramento River and its tributaries was 9,895 in 2010, the lowest on record since 2003 and 76% of the 40 year average of 12,977 (Figure 3). Escapement to the Sacramento River was 4,363. Escapement to Battle Creek was 5,532. Most of the late-fall-run in Battle Creek were counted at Coleman National Fish Hatchery, where the fish propagated.

Winter-run Escapement to the Sacramento River

The estimated escapement of winter-run Chinook salmon to the Sacramento River was 1,596 in 2010. This was the lowest escapement in the last decade, and 17% of the 40 year average of 9,316 (Figure 4).

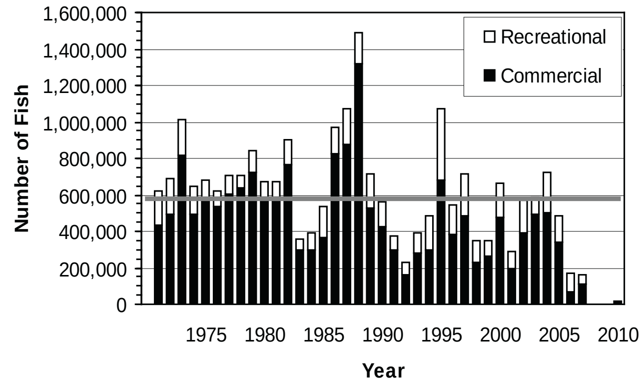

Figure 1 California commercial and recreational Chinook salmon ocean catch from 1971 to 2010 and 40 year average (gray line).

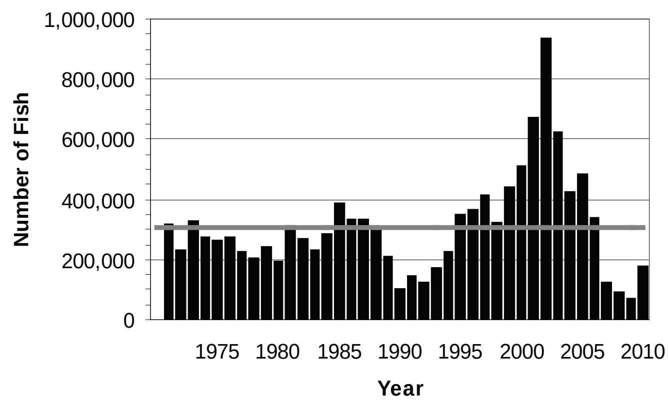

Figure 2 Annual Chinook salmon escapement to the California Central Valley from 1971 to 2010 and 40 year average (gray line)

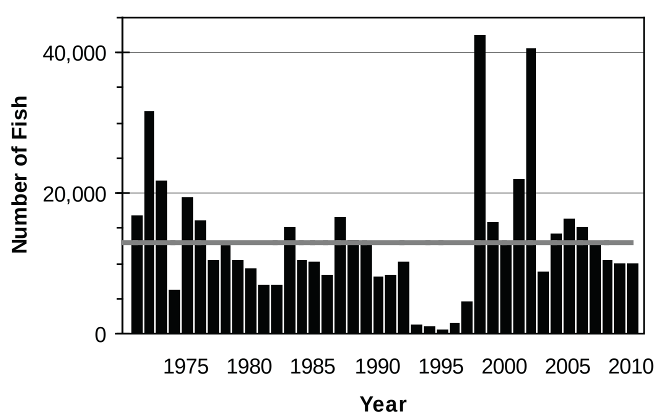

Figure 3 Annual late-fall-run Chinook salmon escapement to the Sacramento River System from 1971 to 2010 and 40 year average (gray line)

Spring-run Escapement to the Sacramento River System

The estimated escapement of spring-run Chinook salmon to the Sacramento River and its tributaries was 3,792 in 2010, the lowest estimate since 1992 and 30% of the 40 year average of 12,632 (Figure 5). The majority of these fish were from Butte Creek and the Feather River Hatchery, with estimates for these locations of 1,160 and 1,661 Chinook salmon, respectively.

Fall-run Escapement to the Sacramento River System

The estimated escapement of fall-run Chinook salmon to the Sacramento River and its tributaries was 152,831 in 2010, the highest since 2006, yet only 60% of the 40 year average of 254,357 (Figure 6). Escapement to the Sacramento River and its tributaries upstream of Red Bluff Diversion Dam (RBDD) was 46,559, 45% of the 40 year average of 102,960 Chinook salmon. Escapement to the Sacramento River and its tributaries between RBDD and Princeton Ferry was 2,858, 12% of the 40 year average of 23,292 Chinook salmon. Escapement to Sacramento River tributaries between Princeton Ferry and Sacramento was 103,414, 81% of the 40 year average of 128,105 Chinook salmon.

Fall-run Escapement to the San Joaquin River System

The estimated escapement of fall-run Chinook salmon to the San Joaquin River and its tributaries was 10,350 in 2010. This was the highest since 2006, but 55% of the 40 year average of 18,984 (Figure 7).

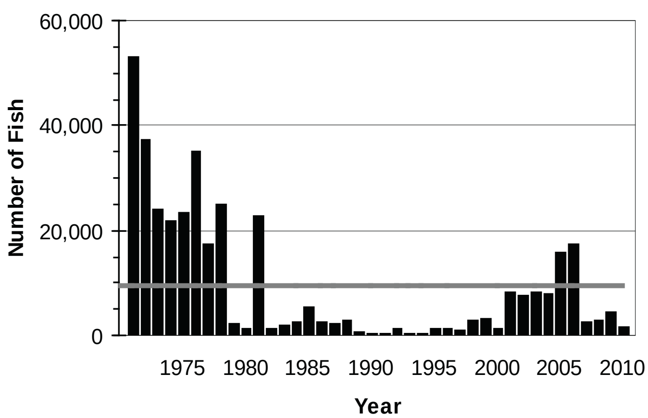

Figure 4 Annual winter-run Chinook salmon escapement to the Sacramento River from 1971 to 2010 and 40 year average (gray line)

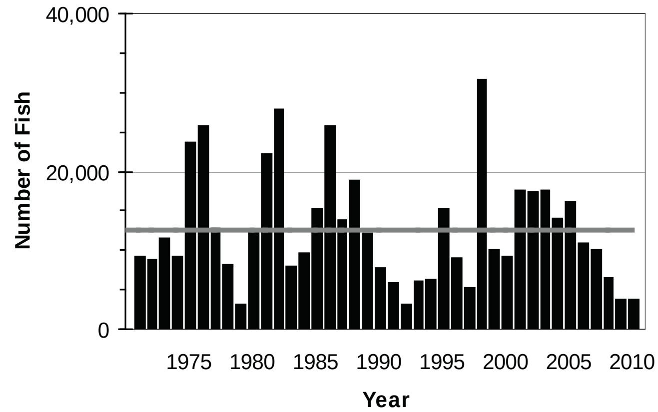

Figure 5 Annual spring-run Chinook salmon escapement to Sacramento River Tributaries from 1971 to 2010 and 40 year average (gray line)

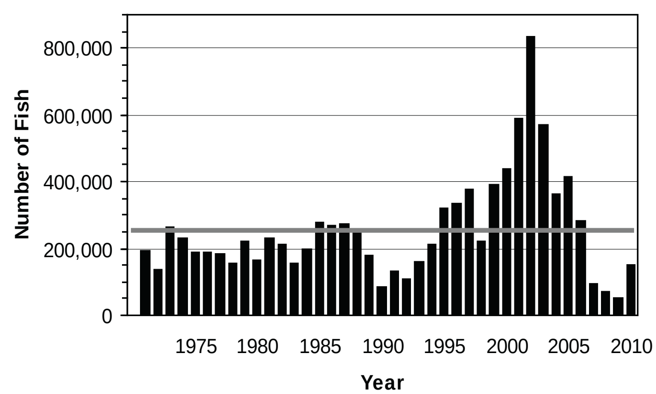

Figure 6 Annual fall-run Chinook salmon escapement to the Sacramento River System from 1971 to 2010 and 40 year average (gray line)

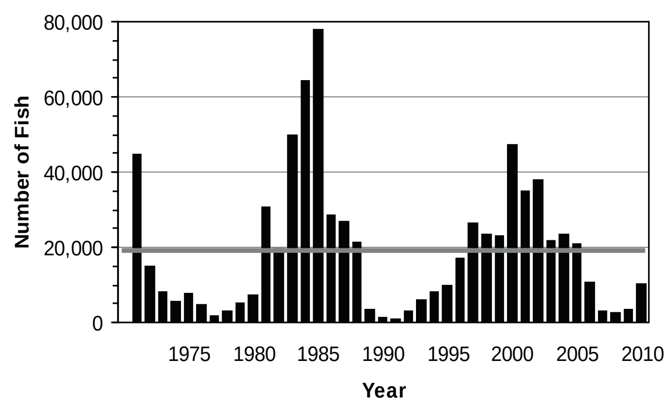

Figure 7 Annual fall-run Chinook salmon escapement to the San Joaquin River system from 1971 to 2010 and 40 year average (gray line)

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Anderson, R. California Department of Fish and Game (CDFG), North Coast Region (NCR).
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Vincik, R.CDFG, NCR.

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Azat, J. 2011. GrandTab 2011.02.01: California Central Valley Chinook Population Database Report. CDFG. Available at http://www.calfish.org/tabid/104/Default.aspx.
Pacific Fishery Management Council. 2011. Review of 2010 Ocean Salmon Fisheries. Prepared for the Council and its advisory entities, 7700 NE Ambassador Place, Suite 101, Portland, Oregon, 97220-1384. Available at http://www.pcouncil.org

Fish Salvage at State Water Project's and Central Valley Project's Fish Facilities during 2010

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Introduction

Two facilities reduce the fish loss associated with water export by the federal Central Valley Project (CVP) and California's State Water Project (SWP). The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) divert (salvage) fish from water exported from the southern end of the Sacramento-San Joaquin Delta.Both facilities use louver-bypass systems to remove fish from the exported water. The diverted fish are periodically loaded into tanker trucks, transported to fixed release sites, and returned to the western Delta. The TFCF began operations in 1957. Operations at the SDFPF began in 1967.

This report summarizes the 2010 salvage information from the TFCF and the SDFPF, and discusses data from 1981 to 2010 for its relevance to salvage trends in recent years. The following species are given individual consideration: Chinook salmon (*Oncorhynchus tshawytscha*), steelhead (*O. mykiss*), striped bass[1] (*Morone saxatilis*), delta smelt[1] (*Hypomesus transpacificus*), longfin smelt[1] (*Spirinchus thaleichthys*), splittail (*Pogonichthys macrolepidotus*), and threadfin shad[1] (*Dorosoma petenense*).

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities. Chinese mitten crab (*Eriocheir sinensis*) were also salvaged. Bypass flows into the fish-collection buildings were subsampled once every 1 to 2 hours for 1 to 45 minutes at the SDFPF and once every 2 hours for 10 to 120 minutes at the TFCF. Fish 20 mm (fork length: FL) or larger were identified and numerated. These fish counts were expanded to estimate the total number of fish salvaged in each 1- to 2-hour period of water export. For example, a sub-sample duration of 10 minutes over a 120-minute salvage period equals an expansion factor of 12. These incremental salvage estimates were then summed across time to develop monthly and annual species-salvage totals for each facility.

Chinook salmon loss estimates are presented because the loss model has been widely accepted and has under-

1. Pelagic Organism Decline (POD) species

gone extensive field validation. Loss is the estimated number of fish entrained by the facility minus the number of fish that survive salvage operations (California Dept. of Fish and Game 2006). Salmon salvage and loss were summarized by origin (i.e., hatchery or wild) and race (fall, late-fall, winter, spring). Race of Chinook salmon is determined solely by criteria based on length and salvage date.

Larval fish (< 20 mm FL) were also collected and examined to determine the presence of sub-20mm delta smelt. Larval sampling at TFCF ran from February 24 through May 23, while it ran from February 20 through June 30, at SDFPF. Larval samples were collected once for every 6 hours of water export. To retain these smaller fish, the fish screen used in the routine counts was lined with a 0.5 mm Nitex net. Larval fish from TFCF were identified to species by TFCF personnel and larval fish from SDFPF were identified to species by California Dept. of Fish and Game personnel.

Water Exports

The SWP exported 3.80 billion m^3 of water in 2010 which was an increase from exports in 2008 (1.45 billion m^3) and 2009 (2.20 billion m^3). Annual SWP exports ranged from 2.96 to 4.97 billion m^3 during the years 2003 through 2007 (Figure 1). The CVP exported 2.86 billion m^3 of water in 2010. CVP exports in 2010 increased from exports in 2009 (2.35 billion m^3) and 2008 (2.24 billion m^3), but were slightly reduced compared to exports in recent years from 2002 to 2007.

The export patterns of the two water projects differed seasonally. Exports reached a maximum in July which was maintained through December at the CVP and in August and December at the SWP (Figure 2). From July-December, 1.85 billion m^3 was exported by the CVP, which represented about 65% of annual export. At SWP, 506 million m^3 was exported in August and 519 million m^3 in December, which represented about 27% of annual export. SWP monthly exports ranged from 50.3 to 519 million m^3. CVP monthly exports ranged from 59.6 to 314 million m^3.

Total Salvage and Prevalent Species

Annual salvage (all species combined including Chinese mitten crab) at the TFCF in 2010 was 1,387,644 (Figure 3). TFCF salvage was an increase from the record-low in 2009 (859,669). Annual salvage at the SDFPF was 2,038,745. SDFPF salvage was an increase from 2009 (837,150) and 2008 (648,797).

Threadfin shad were the most-salvaged species at both facilities (Figure 4 and Table 1). Splittail and American shad were the 2nd and 3rd most-salvaged fish at TFCF. American shad and striped bass were the 2nd and 3rd most-salvaged fish at SDFPF. Relatively few Chinook salmon, steelhead, delta smelt, and longfin smelt were salvaged at the SDFPF (< 0.3% of total annual salvage) and the TFCF (< 0.9% of total annual salvage).

Chinook Salmon

SDFPF salvage (2,624) continued a declining trend which started in 2001 (Figure 5). Salvage of Chinook salmon was similar to 2009 levels (2,463) but was lower than 2008 levels (4,928). Mean 2001-2010 SDFPF salvage was about 9-fold lower than salvage in the 1980's and the late 1990's. Salvage of Chinook salmon at the TFCF (8,119) was higher than in 2009 (4,666) and similar to 2008 (8,786). Mean 2001-2010 TFCF salvage was about 7-fold lower than salvage in the 1980's and the late 1990's.

Salvaged Chinook salmon at TFCF were primarily wild spring-run fish and wild fall-run fish (Table 2). Salvaged Chinook salmon at SDFPF were primarily wild spring-run fish and hatchery winter-run fish. Hatchery winter-run fish comprised 54% of the salvage of hatchery Chinook salmon at the SDFPF. The majority of wild fall-run fish at the SDFPF and TFCF were salvaged in May (Figure 6).

Loss of Chinook salmon (all origins and races) was higher at the SDFPF (11,473) than at the TFCF (6,369; Table 2). Greater entrainment loss at the SDFPF than at the TFCF was attributed to greater pre-screen loss.

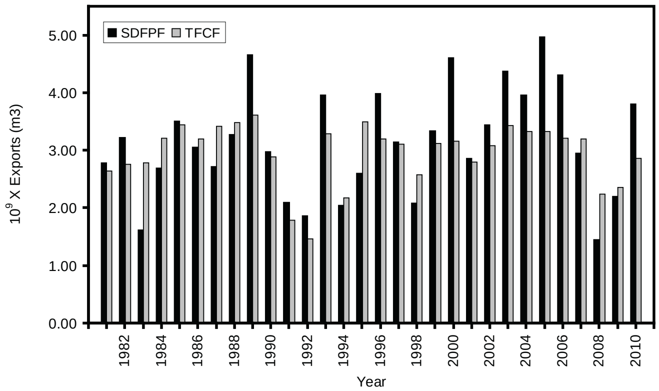

Figure 1 Annual water exports in billions of cubic meters for the SWP and the CVP, 1981 to 2010

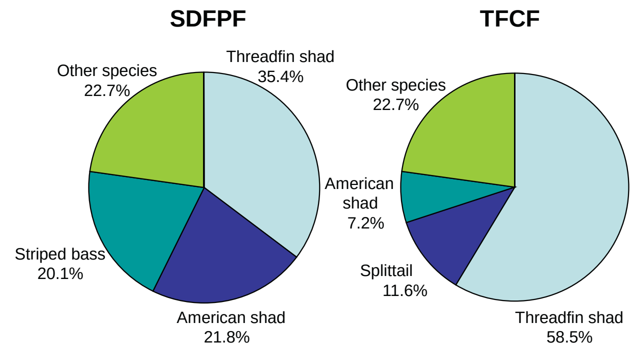

Figure 4 Percentages of annual salvage for the 3 most prevalent species and other species combined including Chinese mitten crab at the TFCF and the SDFPF, 2010

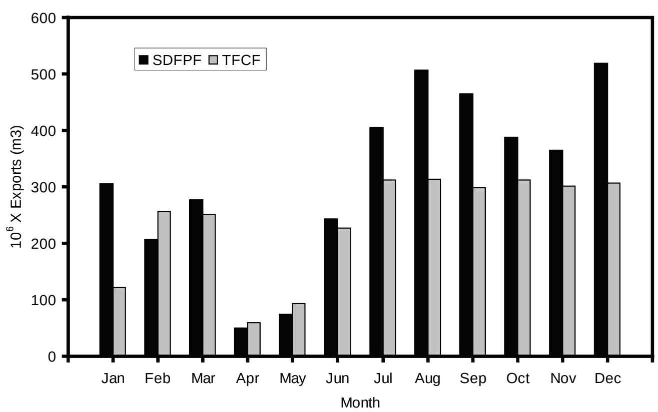

Figure 2 Monthly water exports in millions of cubic meters for the SWP and the CVP, 2010

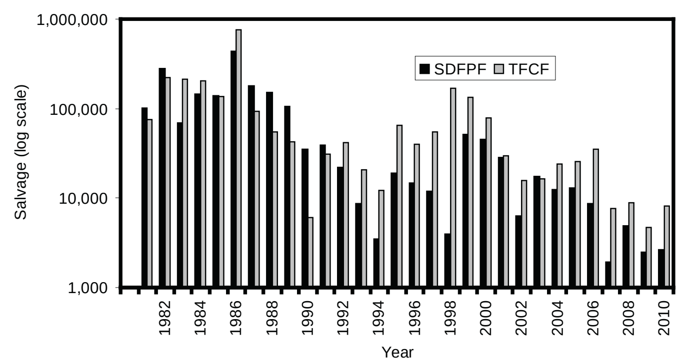

Figure 5 Annual salvage of Chinook salmon (all races and wild and hatchery origins combined) at the SDFPF and the TFCF, 1981 to 2010

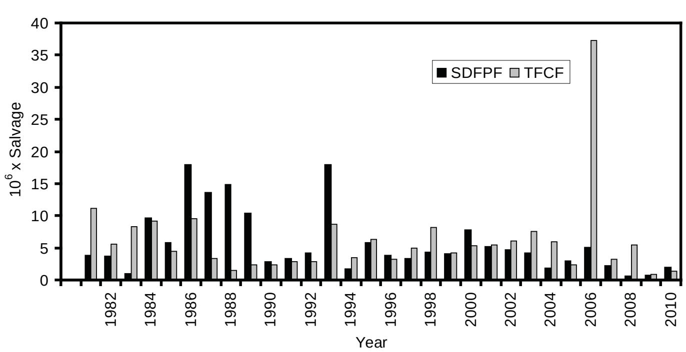

Figure 3 Annual salvage of all taxa combined including Chinese mitten crab at the TFCF and the SDFPF, 1981 to 2010

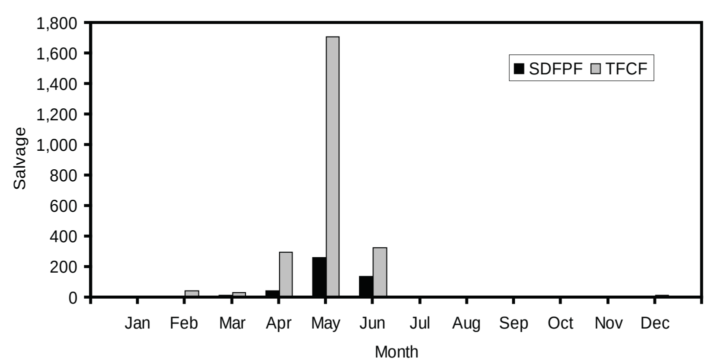

Figure 6 Monthly salvage of wild, fall-run Chinook salmon at the SDFPF and the TFCF, 2010

Table 1 Annual salvage (salvage) and percentage of annual salvage (%) by species including Chinese mitten crab (common name) collected from the SDFPF and TFCF in 2010

TFCF			*SDFPF*		
Species	**Salvage**	**%**	**Species**	**Salvage**	**%**
Threadfin shad	811,164	58.5	Threadfin shad	720,945	35.4
Splittail	161,050	11.6	American shad	445,278	21.8
American shad	99,847	7.2	Striped bass	409,248	20.1
Striped bass	90,328	6.5	Bluegill	336,543	16.5
White catfish	*62,071*	*4.5*	*Inland silverside*	*28,332*	*1.4*
Bluegill	58,410	4.2	Splittail	28,278	1.4
Yellowfin goby	26,404	1.9	White catfish	15,219	0.7
Channel catfish	24,190	1.7	Yellowfin goby	12,488	0.6
Largemouth bass	14,956	1.1	Prickly sculpin	11,234	0.6
Inland silverside	11,753	0.8	Largemouth bass	9,004	0.4
Chinook salmon	8,119	0.6	Channel catfish	5,578	0.3
Shimofuri goby	5,726	0.4	Common carp	3,616	0.2
Prickly sculpin	3,241	0.2	Bigscale logperch	3,146	0.2
Steelhead	3,088	0.2	Chinook salmon	2,624	0.1
Golden shiner	1,556	0.1	Shimofuri goby	2,283	0.1
Unknown lamprey	1,545	0.1	Steelhead	1,545	<0.1
Rainwater killifish	1,125	0.1	Rainwater killifish	774	<0.1
Redear sunfish	882	0.1	Black crappie	769	<0.1
Black crappie	801	0.1	Western mosquitofish	734	<0.1
Western mosquitofish	304	<0.1	Red shiner	297	<0.1
Warmouth	186	<0.1	Lamprey unknown	276	<0.1
Threespine stickleback	171	<0.1	Golden shiner	203	<0.1
Brown bullhead	150	<0.1	Starry flounder	56	<0.1
Delta smelt	95	<0.1	Goldfish	50	<0.1
Common carp	95	<0.1	Riffle sculpin	38	<0.1
Bigscale logperch	87	<0.1	Warmouth	33	<0.1
Tule perch	52	<0.1	Blue catfish	28	<0.1
Black bullhead	41	<0.1	Pacific staghorn sculpin	24	<0.1
Longfin smelt	31	<0.1	Hitch	22	<0.1
Western brook lamprey	28	<0.1	Delta smelt	22	<0.1
Pacific staghorn sculpin	24	<0.1	Redear sunfish	10	<0.1
Sacramento sucker	20	<0.1	Threespine stickleback	9	<0.1
White crappie	20	<0.1	Pumpkinseed	8	<0.1
Starry flounder	16	<0.1	Smallmouth bass	6	<0.1
Red shiner	12	<0.1	Tule perch	5	<0.1
Fathead minnow	8	<0.1	Brown bullhead	4	<0.1
Wakasagi	8	<0.1	Longfin smelt	4	<0.1
Blue catfish	8	<0.1	White sturgeon	4	<0.1
Hitch	5	<0.1	Black bullhead	4	<0.1
Shokihaze goby	4	<0.1	Unknown species	4	<0.1
Green sunfish	4	<0.1	Spotted bass	1	<0.1
Sacramento pikeminnow	4	<0.1			
Goldfish	4	<0.1			
Smallmouth bass	4	<0.1			
Sacramento blackfish	4	<0.1			
Chinese mitten crab	3	<0.1			

Table 2 Chinook salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the SDFPF and the TFCF, 2010

Facility	Origin	Race	Salvage	Percentage	Loss
SDFPF					
	Wild				
		Fall	454	30	*2,057*
		Late-fall	32	2	*135*
		Spring	733	49	*3,234*
		Winter	279	19	*1,218*
	Total Wild		1,498		*6,644*
	Unknown Race		4		*16-17**
	Hatchery				
		Fall	82	7	*351*
		Late-fall	427	38	*1,831*
		Spring	12	1	*51*
		Winter	601	54	*2596*
	Total Hatchery		1,122		*4,829*
	Grand Total		2,624		*11,473*
TFCF					
	Wild	Fall	2,417	35	*1,855*
		Late-fall	172	3	*115*
		Spring	3,335	48	*2,848*
		Winter	969	14	*679*
	Total Wild		6,893		*5,497*
	Hatchery				
		Fall	56	5	*40*
		Late-fall	239	20	*167*
		Spring	30	2	*23*
		Winter	889	73	*634*
	Total Hatchery		1,214		*864*
	Unknown Race		12		*8*
	Grand Total		8,119		*6,369*

** loss range is listed since actual loss could not be calculated due to a missing length (not included in grand total of loss)*

Steelhead

Salvage of steelhead (wild and hatchery origins combined) continued the pattern of mostly low salvage observed since 2005 (Figure 7). Salvage at the SDFPF (1,545) was higher than in 2009 (658). Similarly, TFCF salvage (3,088) was higher than in 2009 (712).

The TFCF salvaged 2,460 hatchery steelhead and 628 wild steelhead. The SDFPF salvaged 1,126 hatchery steelhead and 419 wild steelhead.

Salvage of wild steelhead at both facilities occurred predominantly in the first half of the year (Figure 8). Wild steelhead were salvaged January-June and in October and December (2) at the SDFPF and January-June at the TFCF. Wild steelhead at both facilities were salvaged most frequently February-March.

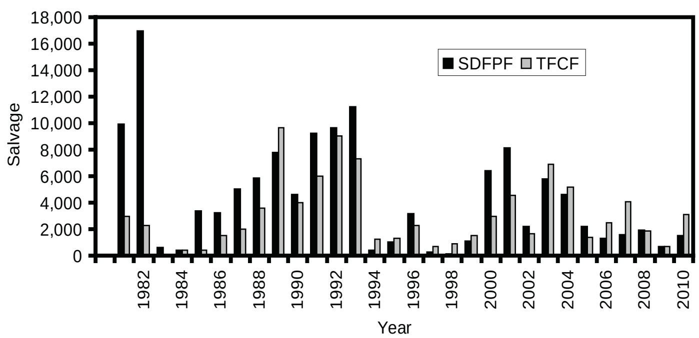

Figure 7 Annual salvage of steelhead (wild and hatchery origins combined) at the SDFPF and the TFCF, 1981 to 2010

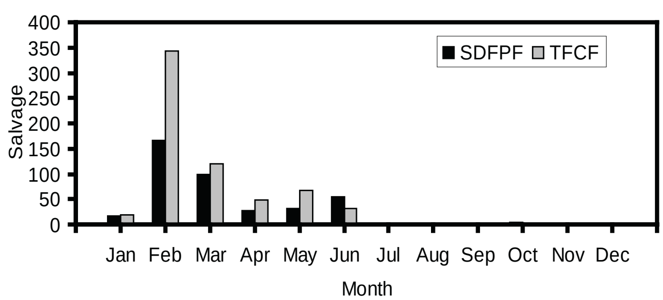

Figure 8 Monthly salvage of wild steelhead at the SDFPF and the TFCF, 2010

Striped Bass

Salvage at the TFCF (90,328) was a near record-low. Salvage at the TFCF and SDFPF (409,248) continued the generally-low trend observed since the mid-1990's (Figure 9). Prior to 1995, annual striped bass salvage was generally above 1,000,000 fish.

Most striped bass salvage at the SDFPF occurred in June and July, whereas most striped bass salvage at the TFCF was observed in March and June (Figure 10). At the SDFPF, June salvage (175,033) and July salvage (122,493) accounted for 73% of annual salvage. At the TFCF, salvage during March (20,639) and June (20,669) accounted for 46% of annual salvage. Striped bass were salvaged every month at both facilities, with the lowest monthly salvage occurring in May at both the SDFPF (71) and the TFCF (253).

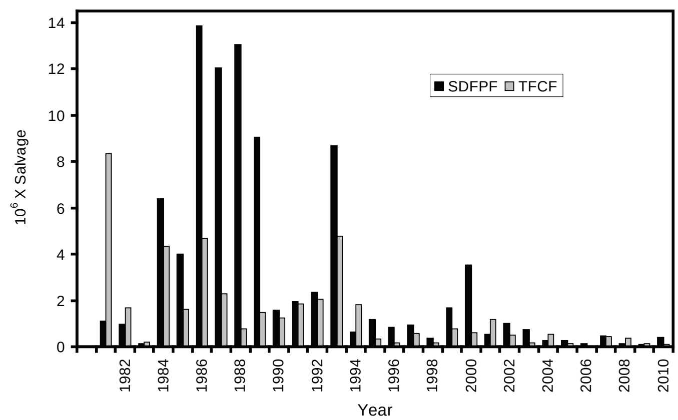

Figure 9 Annual salvage of striped bass at the SDFPF and the TFCF, 1981 to 2010

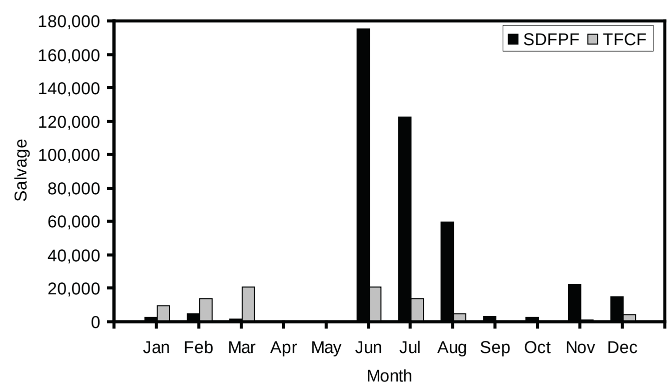

Figure 10 Monthly salvage of striped bass at the SDFPF and the TFCF, 2010

Delta Smelt

Record-low numbers of delta smelt were salvaged at both facilities (Figure 11). Salvage at the SDFPF (22) was lower than in 2009 (479). Salvage at the TFCF (95) was also lower than in 2009 (286).

Most delta smelt were salvaged in a few months during the first half of the year (Figure 12). Adult delta smelt were only salvaged in March (16) at the SDFPF, which accounted for 73% of the total annual salvage. Juvenile delta smelt were only salvaged in June (6) at the SDFPF. Adult delta smelt were most-frequently salvaged in February (44) at the TFCF, which accounted for 46% of the total annual salvage. Juvenile delta smelt were only salvaged in May (23) at the TFCF.

Only 1 delta smelt less than 20 mm was detected at the TFCF. Delta smelt less than 20 mm were first detected on June 3 at the SDFPF and were observed 9 days there.

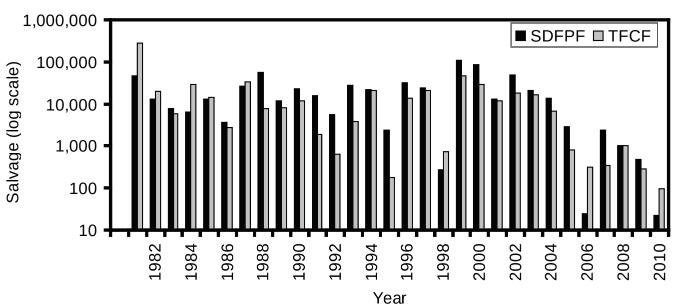

Figure 11 Annual salvage of delta smelt at the SDFPF and the TFCF, 1981 to 2010

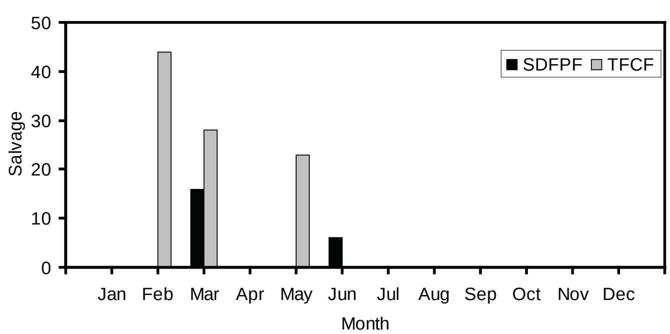

Figure 12 Monthly salvage of delta smelt at the SDFPF and the TFCF, 2010

Longfin Smelt

Longfin smelt at both facilities continued to be salvaged at very low levels compared to the early 2000s and the late 1980s (Figure 13). Salvage at the SDFPF (4) was lower than at the TFCF (31).

No adult longfin smelt were salvaged at either facility. Juvenile longfin smelt were only salvaged in May (4) at the SDFPF. Juvenile longfin smelt were salvaged in April (3) and May at the TFCF. The salvage of juvenile longfin smelt peaked in May (28) at the TFCF, which accounted for 90% of salvage. Only 1 longfin smelt less than 20 mm was detected at the TFCF. No longfin smelt less than 20 mm were detected at the SDFPF.

Splittail

Salvage of splittail at both facilities was higher than in 2009 (Figure 14). Salvage at the SDFPF (28,279) was higher than in 2009 (1,418). Salvage at the TFCF (161,050) was substantially higher than in 2009 (1,405). Splittail salvage has followed a boom-or-bust pattern, often varying year to year by several orders of magnitude.

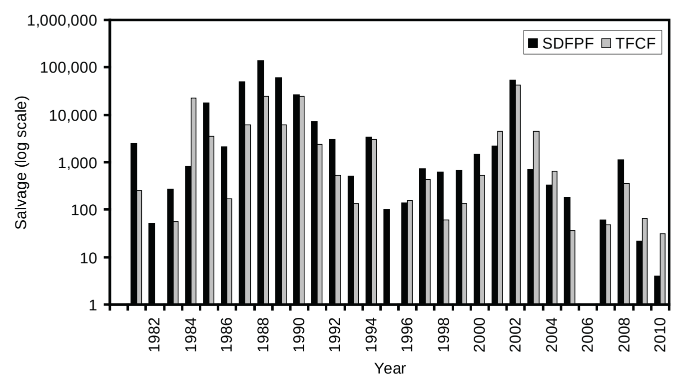

Figure 13 Annual salvage of longfin smelt at the SDFPF and the TFCF, 1981 to 2010

Threadfin Shad

Annual salvage at the SDFPF (720,945) was lower than at the TFCF (811,164) (Figure 15). Salvage at the SDFPF was higher than in 2009 (387,940). Similarly, TFCF salvage was higher than in 2009 (401,911). Similar to splittail, annual salvage of threadfin shad has varied greatly through time.

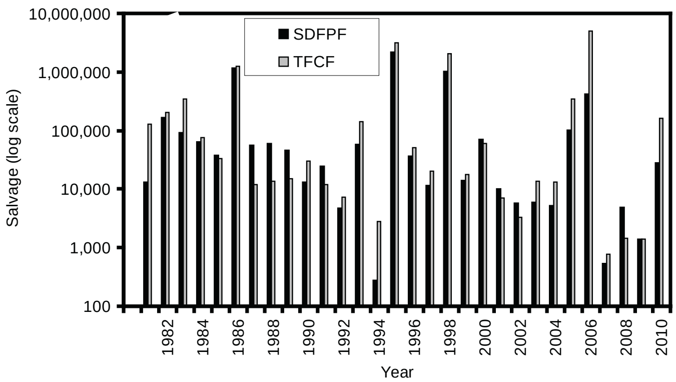

Figure 14 Annual salvage of splittail at the SDFPF and the TFCF, 1981 to 2010

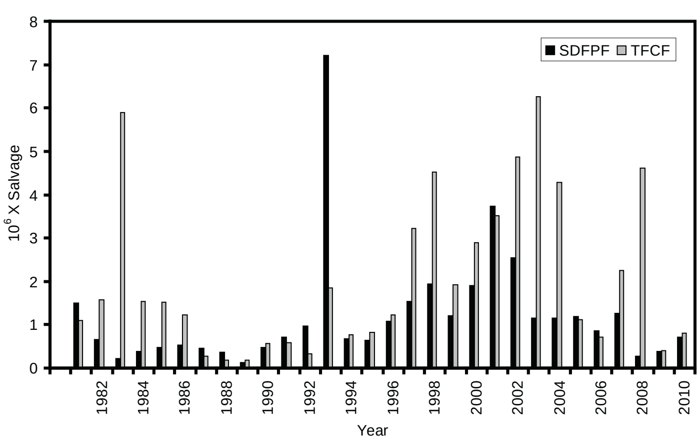

Figure 15 Annual salvage of threadfin shad at the SDFPF and the TFCF, 1981 to 2010

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Status and Trends of San Francisco Estuary White Sturgeon

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Introduction

The California Department of Fish and Game's (CDFG) sturgeon population study (study) develops data and collects information to assess the suitability of fishing regulations, to determine progress towards management objectives, and to contribute to the understanding of how sturgeon populations respond to changes in environmental conditions.

The study uses mark-recapture methods to develop information on the absolute abundance, harvest rate, and survival rate of white sturgeon (*Acipenser transmontanus*) and — to a much lesser extent due to scarcity of individuals — of green sturgeon (*A. medirostris*). The metrics require a minimum of 1-3 years to develop and broad confidence intervals around most of the estimates are attributable in large part to relatively small sampling effort. We do not know the degree to which these estimates violate pertinent assumptions for mark-recapture studies (Ricker 1975), but the metrics have critical management utility.

The study also uses the reported catch and catch per unit effort (CPUE) of sturgeon by the Commercial Passenger Fishing Vessel (CPFV) fleet, an index of age-0 white sturgeon year class strength from the San Francisco Bay Study, length data from Sturgeon Fishing Report Cards and during tagging, and CPUE during tagging. Taking just 1-2 years to develop and speaking to a large fraction of the sturgeon age distribution, these are important and complementary metrics.

With green sturgeon listed under the federal Endangered Species Act and San Francisco Estuary white sturgeon the object of an important sport fishery while classified as *conservation dependent* by the American Fisheries Society (Musick et al. 2000), we are striving to improve some aspects of the sturgeon population study. We are (accordingly) in the midst of an in-depth exploration of extant and alternative methods, but we avoid much discussion about analytical methods here. Instead, we include citations to a number of memo reports for those who are interested in details.

Status and Trends

Year-class Strength

The years 1998 and 2006 were the two most-recent 'notably strong' year classes as indexed by catch from the San Francisco Bay Study (Figure 1). See Fish (2010) for methods and the relationship between year-class indices and Delta outflow.

Length Frequencies

The length-frequency distribution from catch during tagging — using trammel nets that select for fish between roughly 102 centimeters total length (cm TL) and 183 cm TL — shows modes at around 110 cm TL and around 180 cm TL (Figure 2) corresponding to the relatively-strong late-1990s year classes and the record-strong early-1980s year classes that have been depleted through three decades of mortality (Schaffter and Kohlhorst 1999; Fish 2010).

The length-frequency distribution from Sturgeon Fishing Report Cards (which is negatively biased for fish between 117 cm TL and 168 cm TL) shows modes around 60, 110, and 180 cm TL (Figure 3) that correspond to the relatively strong 2006, late-1990s, and record-strong early-1980s year classes. See DuBois et al. (2011, 2010a, and 2009) and Gleason et al. (2008) for more information on data from Sturgeon Fishing Report Cards.

Relative Abundance

Although not designed as a catch per unit effort (CPUE) study *per se*, we consider CPUE during tagging to be an index of abundance and it is positively correlated with estimated abundance via mark-recapture when years 1984, 1985, and 1994 are excluded (all years: $r=0.1805$, $p=0.49$; less years 1984, 1985, and 1994: $r=0.6445$, $p=0.013$). The period 2000-2009 included a near-record low value (the year 2005; Figure 4) and all values fell below the historical average. See DuBois et al. (2010b), DuBois and Mayfield (2009a; 2009b), Schreier and Donnellan (2007), and Donnellan and Gingras (2007) for more information on tagging CPUE.

The CPFV fleet is not obligated to speciate or to record the lengths of captured sturgeon, but we believe most are legally-harvested white sturgeon. Sturgeon CPUE during tagging and from the CPFV fleet are positively correlated ($r=0.5793$, $p=0.019$). The period 2000-2008 included a near-record low value for CPFV CPUE (the year 2005; Figure 5) and an increasing trend. See DuBois (2011a) for more information about CPFV CPUE.

Harvest and Survival Rates

Annual harvest rate is calculated from the number of tagged sturgeon reported caught by the public within one year of application and the number of tags applied during field sampling initiating the annual time period. Due to variations in the lengths of fish tagged during the course of the study and of fish legally harvested, we can only calculate harvest rate for certain population segments. The harvest rates of fish 117-168 cm TL (i.e., the legally-harvestable size as of March 2007 and a subset of all prior legal sizes) during 2000-2008 were generally lower than rates during the 1980s (Figure 6). See DuBois (2011b) for more information about harvest rate.

Annual survival rate is calculated from catch curves through the use of lengths of fish captured during tagging (DuBois et al. 2010) and/or from tags returned to us by the public (Ricker 1975). The period 2000-2008 included annual rates near the average (Figure 7). The survival rates from tag returns are for fish legal to harvest at tagging and are sometimes impossibly high due to small sample sizes and/or recruitment. Survival rates from catch curves include error attributable to variations in recruitment. See DuBois (2011b) for more information about survival rate.

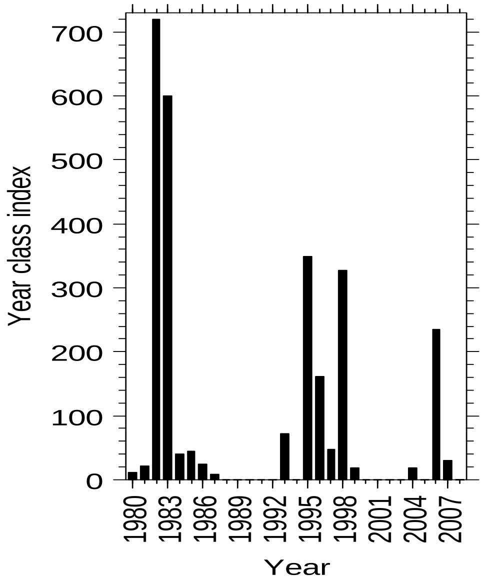

Figure 1 Time series (1980-2008) of San Francisco Bay Study white sturgeon year-class indices (Fish 2010); index is zero in years for which no bar appears (N=12)

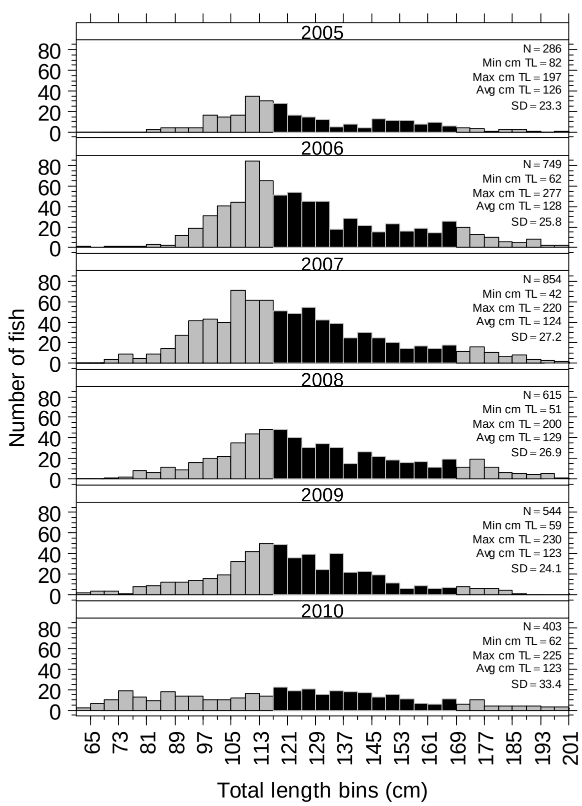

Figure 2 Length frequency distributions from the six most recent years of tagging (2005-2010); dark bars denote the current legally-harvestable size range (117-168 cm TL); fish less than 61 cm TL (N=12) and fish greater than 200 cm TL (N=12) are not included in graphics.

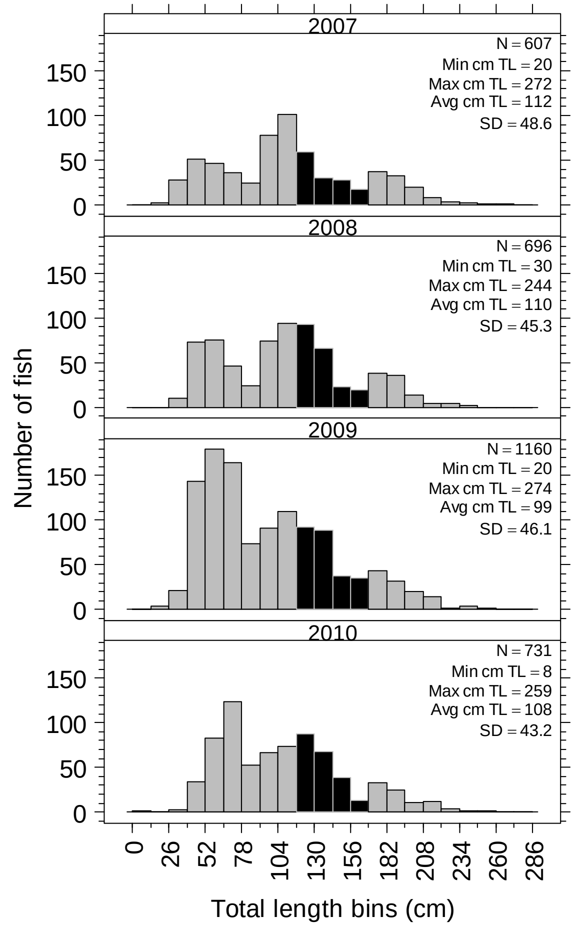

Figure 3 Length frequency distributions from the four years of California Sturgeon Fishing Report Card data (2007-2010); dark bars denote the current legally-harvest-able size range (117-168 cm TL)

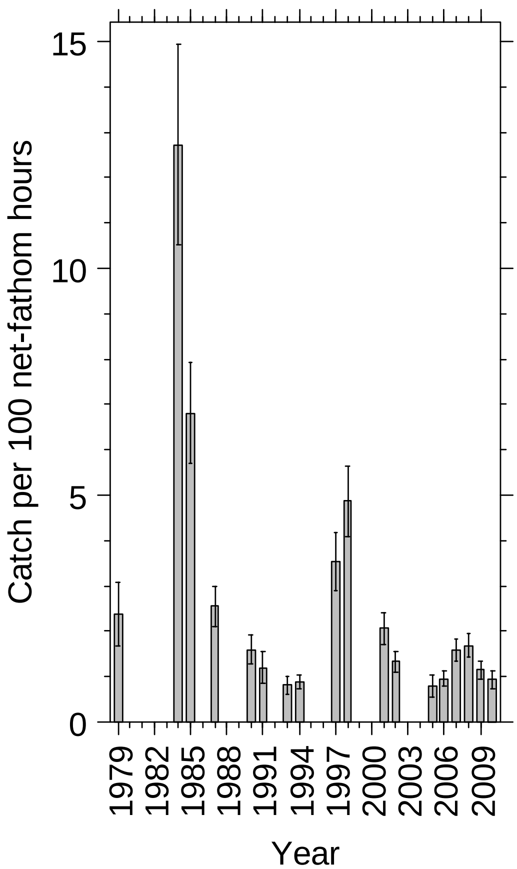

Figure 4 Time series (1979-2010) of catch per 100 net-fathom hours from tagging with 95% Confidence Intervals for fish within the current legally-harvestable size range (117-168 cm TL) and years in which tagging occurred.

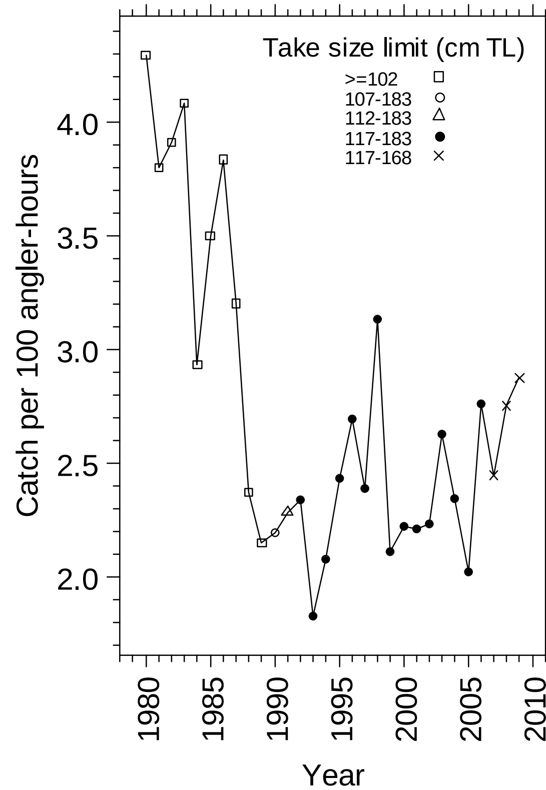

Figure 5 Time series (1980-2009) of Commercial Passenger Fishing Vessel fish kept (catch) per 100 angler-hours within the San Francisco Estuary (successful trips only); symbols denote change in legal size limit over the years

Abundance

Using Petersen mark-recapture methods we directly estimate the annual abundance of some population segments (i.e., based on a length range or lower length limit). We indirectly estimate abundance for other population segments by considering the length-frequency distribution of catch during tagging, the relationship between length and age, and the direct estimates.

The period 2000-2009 included near-record low abundance of white sturgeon ≥ 102 cm TL (Figure 8) and 3,252-6,539 age-15 fish as estimated (in full or part) using the indirect approach. The abundance of age-15 fish is the metric by which progress toward Central Valley Project Improvement Act (CVPIA) recovery goal (11,000 fish) is assessed. See DuBois (2011c) for more information about abundance.

Discussion

It is important to consider all available data (both dependent on and independent of the fishery) when evaluating the status of white sturgeon and management actions, because all of it is subject to uncertainty, some of it is subject to high uncertainty, and much of it (e.g., survival rate and abundance) is crucial for effective conservation and management.

We (and the sturgeon biologists who predated us) used a complicated mark-recapture algorithm to estimate abundance. The algorithm includes periodic updates using recapture data collected up to several years after tagging, assumptions about growth rate and about mortality attributable to tagging, and more professional judgment than we'd like. Although trends in mark-recapture abundance and in measures of relative abundance are generally harmonious, the mark-recapture abundance estimates are imprecise, and we have little ability to evaluate the accuracy of historical estimates. However, we have developed a new algorithm to estimate abundance — one that uses harvest rate from tagging and harvest from Sturgeon Fishing Report Cards — that is precise, with which we can evaluate the accuracy of corresponding estimates from the mark-recapture algorithm, and about which we will report in the near future.

Central Valley Project Improvement Act 's objective of a sustained increase in the number of age-15 fish (an index of adult fish productivity) to 11,000 is the only quantitative management objective for white sturgeon in California. It has not been achieved nearly 2 decades after being established. Given the apparent size of recent year classes as well as recent survival rates, harvest rates, indices of abundance, and length-frequency distributions, it is plausible (we plan to model this) that the number of age-15 fish will not increase to 11,000 for many years. That said, qualitative and intuitive management objectives — such as avoiding a petition to list under ESA, the presence of several relatively strong year classes, and harvest broadly allocated amongst user groups (Gleason et a. 2008; DuBois et al. 2009; DuBois et al. 2010a; DuBois et al. 2011) — have been achieved and appear sustainable for the foreseeable future.

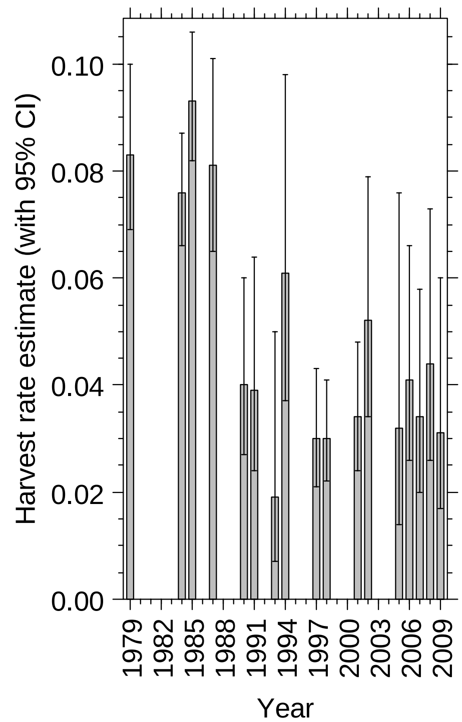

Figure 6 Time series (1979-2009) of harvest rate estimates with 95% Confidence Intervals for fish within current legally-harvestable size range (117-168 cm TL)

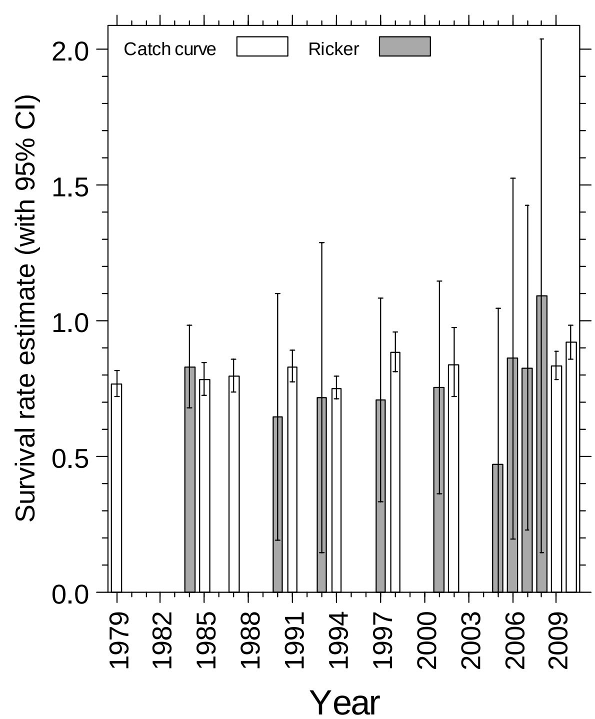

Figure 7 Time series (1979-2010) of survival rate estimates with 95% Confidence Intervals; note the two methods used to estimate rates; lower 95% CI for 2005 = -0.101, upper 95% Confidence Intervals for 2008 = 2.038

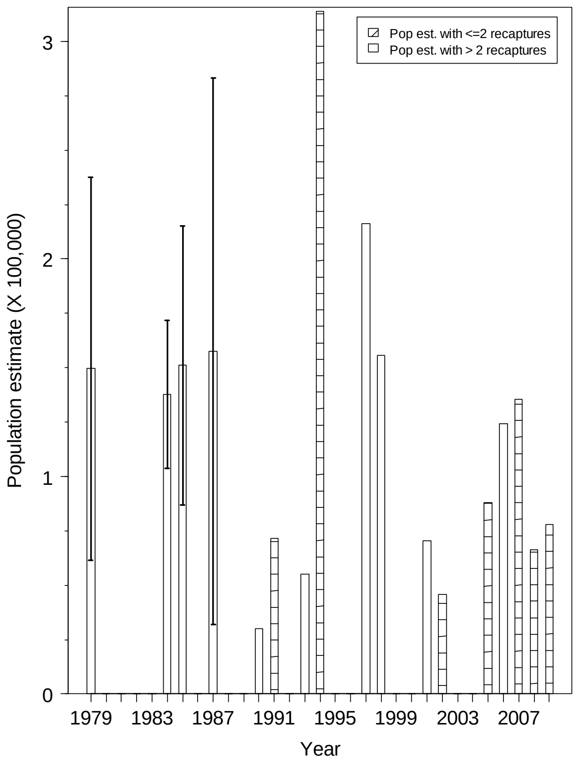

Figure 8 Time series (1979-2009) of population estimates fish≥ 102 cm TL; 95% Confidence Intervals are not shown for estimates made using the indirect approach

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■ Interagency Ecological Program for the San Francisco Estuary ■

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